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SPEECH MOTOR DEVELOPMENT

OF AFRIKAANS SPEAKING

CHILDREN

AGED FOUR TO SEVEN YEARS

By

ISABELLA JOHANNA GROBLER

Presented in partial fulfillment of the requirements for the MCommunication Pathology Degree in the Department of Communication Pathology, Faculty of Arts, University of Pretoria, Pretoria, South Africa

March, 2000

The Financial Assistance of the Centre for Science Development, (HSRC, South Africa) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily attributed to the Centre for Science Development.

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ACKNOWLEDGEMENTS

I would like to thank the following people sincerely for their contributions:

-My dear husband, Johan, for his unparalleled patience, love and encouragement throughout the completion period and his tremendous help with every single step of this project. "This is your dissertation as much as mine, thanks....".
-Prof. Anita van der Merwe for numerous hours spent on lengthy drafts and her competent and patient guidance.
-Mrs. Emily Groenewald for assistance with the spectrographic analysis and method and for being such a gift of encouragement.
-My dear parents, brother, grandmother and parents-in-law who persevered in believing that I could do this.
-My friends, Rika, Hantie and Annalése for the special kind of support and encouragement only wonderful friends can provide.
-My father, mother and Annalése for their help with the preparation of the final draft and the handing-in process.
-All the subjects and their parents for their willingness to partake in this study.
-Mr.H.Tessner for his input with the phonetic transcription and word syllable structure analysis and Miss.R.Ehlers and Dr.M.van der Linde for their statistical input.
-Paul and Vonda Kooima for their contribution to the printing of the dissertation.

Above all:

"I will praise you, O Lord, among the nations; I will sing of you among the peoples. For great is your love, reaching to the heavens; your faithfulness reaches to the skies. Be exalted O God, above the heavens; let your glory be all over the earth." (Ps.57:9-11)

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SUMMARY

SPEECH MOTOR DEVELOPMENT OF AFRIKAANS SPEAKING CHILDREN AGED FOUR TO SEVEN YEARS

by

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The limited amount of normative information regarding speech motor development in the clinically important age range four to seven years served as motivation for this study. The main aim of the study was to collect normative information regarding sensorimotor speech control skills of pre-school children.

The method of the study was designed and the results interpreted within the framework of the four-level model of speech production of Van der Merwe (1997). Basic qualitative and quantitative data were gathered for a variety of aspects of speech motor development in Afrikaans-speaking children aged 4;0 to 6;7 years in the following areas: 1) non-speech oral movements, 2) non-speech diadochokinesis, 3) speech diadochokinesis, 4) cluster production, 5) word syllable structure in spontaneous speech, 6) acoustic data regarding first-vowel duration and variability of first-vowel duration in repeated utterances of the same word, 7) acoustic voice onset time data, 8) acoustic data regarding first-syllable duration in words of increasing length.

Results indicated that associated movements and accuracy errors occurred in some non-speech oral movement and non-speech diadochokinesis tasks.

Normative, diadochokinetic rate data were gathered. Perceptual analysis indicated difficulty with glottal and three-place diadochokinesis tasks. Subjects produced 84% of initial clusters in isolation correctly and 79% of final clusters. Schwa-vowel insertions occurred in clusters in isolation, but not in spontaneously produced words. Subjects produced 163 different word syllable structures in spontaneous speech, with 18 structures occurring in all subjects' data. Six-year-olds generally displayed the shortest first-vowel duration. Individual, non-age related trends occurred for variability of first-vowel duration. Mean voice onset times in voiced stop contexts ranged from –97ms to +12ms, with overall instances of mean voicing lead occurring in 27% of the four-year-olds' productions, 4% of the five-year-olds' productions and 80% of the six-year-olds' productions. Mean voice onset times in voiceless stop contexts ranged from +11ms to +37ms. Subjects adapted first-syllable duration to word length by decreasing it as the word length increased.

Results indicated that a wide range of normal speech motor performance is possible for children this age, and that individuals can display different performance levels for different speech parameters. This emphasizes the complexity of speech motor development and the need to assess a variety of speech motor parameters. It is essential that quantitative (objective) analysis of children's speech motor performance be supplemented with qualitative (descriptive) analysis. The study contributed knowledge to the understanding of certain aspects of speech motor development and to the speech production process in general.

Key words: *sensorimotor speech control, speech motor development, non-speech oral movements, non-speech diadochokinesis, speech diadochokinesis, cluster production, word syllable structure, vowel duration, variability of vowel duration, voice onset time, first-syllable duration in words of increasing length*

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SAMEVATTING

SPRAAKMOTORIESE ONTWIKKELING VAN VIER- TOT SEWEJARIGE AFRIKAANSSPREKENDE KINDERS

deur

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Die beperkte mate van normatiewe spraakmotoriese inligting vir kinders in die belangrike kliniese ouerdomsinterval vier to sewe jaar, het as motivering vir hierdie studie gedien. Die hoofdoel van die studie was die versameling van normatiewe inligting rakende sensories-motoriese spraakvaardighede van voorskoolse kinders.

Die metode van die studie is beplan en die resultate geïnterpreteer binne die raamwerk van die vier-vlak model van spraakproduksie deur Van der Merwe (1997). Basiese kwalitatiewe en kwantitatiewe data is versamel vir 'n verskeidenheid van spraakmotoriese aspekte in normale, 4;0 tot 6;7-jarige Afrikaanssprekende kinders in die volgende areas: 1) nie-spraak orale bewegings, 2) niespraak diadokokinese, 3) spraak-diadokokinese, 4) produksie van klankkombinasies, 5) woordlettergreepstruktuur in spontane spraak, 6) akoestiese data rakende duur van die eerste vokaal en variasie daarvan in herhaalde uitinge, 7) akoestiese stemaanvangstyddata, 8) akoestiese data rakende die duur van die eerste lettergreep in woorde van toenemende lengte.

Geassosieerde bewegings en akkuraatheidsfoute het voorgekom in sommige nie-spraak orale bewegingstake en nie-spraak diadokokinesetake. Diadokokinese-spoed-inligting is versamel. Perseptuale analise het probleme met veral glottale- en drie-plek diadokokinese geïdentifiseer. Proefpersone het 84% van inisiële klankkombinasies korrek geproduseer en 79% van finale klankkombinasies. Schwa-vokaalinvoegings het voorgekom in produksies van klankkombinasies in isolasie maar nie in spontane spraak nie. 'n Verskeidenheid van 163 woordlettergreepstrukture is geproduseer, waarvan 18 in al die proefpersone se data voorgekom het. Sesjariges het die kortste eerste-vokaalduur vertoon. Individuele, nie-ouderdomsverwante tendense was teenwoordig vir variasie van eerste-vokaalduur. Gemiddelde stemaanvangstydwaardes vir stemhebbende afsluitingsklankkontekste het gestrek vanaf –97ms tot +12ms. Vierjariges het stemvoorloop vertoon in 27% van hulle gemiddelde stemaanvangstydwaardes vir stemhebbende afsluitingsklanke, teenoor vyfjariges se 4% en sesjariges se 80%. Gemiddelde stemaanvangstydwaardes vir stemlose afsluitingsklanke het gestrek vanaf +11ms tot +37ms. Proefpersone het die duur van die eerste lettergreep aangepas by toenemende woordlengte deur duur te verminder soos wat die woord verleng.

Die bevindinge van die studie dui daarop dat 'n wye omvang van normale spraakmotoriese gedrag kan voorkom by kinders van hierdie ouderdom en dat individue verskillende prestasievlakke kan toon vir verskillende spraakparameters. Resultate beklemtoon die kompleksiteit van spraakmotoriese ontwikkeling en die belang daarvan om 'n verskeidenheid van parameters te evalueer. Dit is essensieël dat kwantitatiewe (objektiewe) analise van kinders se spraakmotoriese gedrag aangevul word met kwalitatiewe (beskrywende) analise. Hierdie studie dra by tot die begrip van sekere aspekte van spraakmotoriese ontwikkeling en spraakproduksie in die algemeen.

Sleutelterme: *sensories-motoriese spraakvaardighede, spraakmotoriese ontwikkeling, nie-spraak orale bewegings, nie-spraak diadokokinese, spraak-diadokokinese, produksie van klankkombinasies, woordlettergreepstruktuur, vokaalduur, stemaanvangstyd, eerste-lettergreepduur in woorde van toenemende lengte.*

CONTENTS

CONTENTS

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CONTENTS

(-CONTINUED)

CONTENTS

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CONTENTS

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LIST OF TABLES

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LIST OF TABLES

(CONTINUED)

LIST OF TABLES

(CONTINUED)

LIST OF TABLES

(CONTINUED)

LIST OF FIGURES

LIST OF FIGURES

(CONTINUED)

Page

CHAPTER 4

LIST OF FIGURES

(CONTINUED)

LIST OF ABBREVIATIONS

2S-OM:	Two-sequence oral movements
3S-OM:	Three-sequence oral movements
ARW:	Afrikaanse Reseptiewe Woordeskattoets
C:	Consonant
cm:	Centimeters
CPG:	Central pattern generator
CfV:	Coefficient of variation
DAS:	Developmental apraxia of speech
dB:	Decibel
DDK:	Diadochokinesis
DDR:	Diadochokinetic rate
DSD:	Developmental speech disorders
DSP:	Digital signal processor
DPD:	Developmental phonological disorders
DVD:	Developmental verbal dyspraxia
EMG:	Electromyogram
EMMA:	Electro-magnetic midsaggital articulometer
EP:	Error percentage
F:	Formant
FCL:	Final consonant clusters
FSD:	First-syllable duration
FVD:	First-vowel duration
GDDK:	Glottal diadochokinesis
Hz:	Hertz
ICL:	Initial consonant clusters
I-OM:	Isolated oral movements
LDDK:	Lip diadochokinesis
LPC:	Linear predictive coding
Max.:	Maximum
Min.:	Minimum
ms:	Milliseconds

LIST OF ABBREVIATIONS

(CONTINUED)

n:	Number
NSO-DDK:	Non-speech oral diadochokinesis
NSOM:	Non-speech oral movements
PC:	Percentage correct
POO:	Percentage of occurrence
rep/sec:	Repetitions per second
S:	Subject
SD:	Standard deviation
S-DDK:	Speech diadochokinesis
sec:	Second
STDEV:	Standard deviation
TFS:	Total functional score
TDDK:	Tongue diadochokinesis
TM:	Target movement
V:	Vowel
VDDK:	Velar diadochokinesis
VOT:	Voice onset time
Wg:	Word group
yrs:	Years

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CHAPTER 1

ORIENTATION AND PROBLEM STATEMENT

1. 1. INTRODUCTION AND PROBLEM STATEMENT

"If speech is so easy, should not the study of speech be easy? The higher we look into the central nervous system, however, the less we know." (Borden & Harris, 1980:47).

Most children acquire speech in an apparently effortless way. Normal adults produce speech skillfully, aware only of aspects such as the intent or meaning behind words, the search for appropriate words to express this meaning, and maybe emotions concerning the topic or the listener (Borden & Harris, 1980). The apparent ease and unconscious manner with which speakers produce speech, may lead to the assumption that speech production is a simple, 'easy' process and an equally 'easy' field of study. Yet, scientists studying motor control often refer to speech production as a supreme example of skilled behavior (Smith & Goffman, 1998). Similarly, speech language pathologists have come to appreciate the complexity of sensorimotor speech production when faced clinically with the awesome task of helping clients acquire and restore these skills. Clinicians are daily confronted with children who do not seem to acquire speech easily, and adults who have lost the ability to produce speech effortlessly. While a fair amount of information is available regarding the development and control of linguistic, cognitive, perception and physiological processes underlying speech production, less is currently known about the nature of sensorimotor control of speech movements in children. While sensorimotor control of speech movements has long been a focus of study in normal adult speakers, researchers are only beginning to gain more information about the sensorimotor control processes underlying normal speech development. "What we have are only the barest outlines of a complex, multidimensional picture." (Smith, Goffman & Stark, 1995:95). Consequently, clinicians dealing with pathological communication/speech development can currently only make limited deductions about the nature of children's sensorimotor speech control status, with a resulting negative impact on diagnostic and treatment decisions. Several theoretical and practical issues contribute to the current unfortunate situation and need to be considered when planning research about speech motor development. These issues will be delineated in the ensuing discussion.

The need to focus research on the sensorimotor nature or motor control aspects of speech production and development, has increasingly been voiced by clinicians working with different types of developmental speech and language disorders. "In many childhood speech and language disorders the potential role of a motor component is often discussed." (Smith et al.,1995:87). For example, in the case of developmental apraxia of speech (DAS), which is a controversial disorder with conflicting theories about its aetiology, definition and differential diagnostic characteristics, authors of contrasting theoretical orientations alike, refer to some kind of motor control problem as part of the symptom pattern (e.g. Morley,1972; Rosenbek & Wertz,1972). Yoss and Darley (1974:399) described DAS as a "....difficulty in programming the speech musculature for volitional production of phonemes.". Crary, Landess and Town (1984:169) called it an "...expressive linguistic disturbance..." stating that "The linguistic problems described may be related to underlying sensory motor deficits.....". Milloy and Morgan-Barry (1990:121) again believed that "Motor planning....appears to be unreliable...." in children with DAS. Love (1992:107) argued that "...a strong argument can be made that the critical sign of the disorder is poor motor programming in speech movements and/or oral movements.". Others view DAS as: "....a disorder of motor control of speech production, not attributable to other problems of muscular control." (Hall, Jordan & Robin,1993:8). Stuttering in children is another disorder that is frequently associated with the abnormal development of speech motor skills (Sharkey & Folkins,1985; Riley & Riley,1986; Adams,1987; Peters & Starkweather,1990; Bishop, Williams & Cooper,1991). In specific language impairment where expressive speech and language skills are compromised, some researchers have found it reasonable to suggest that a subtle motor deficit may contribute to the disorder (e.g. Smith et al.,1995). Others have argued that developmental phonological disorders (DPD) in some cases may reflect deficits in sensorimotor speech processes (e.g. Kent &

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Forner,1980; Leonard,1985; Tyler, Edwards & Saxman,1990). Bradford and Dodd (1994:354) for example, suggested that "...there may be a sub-group of phonologically disordered children whose speech is characterized by inconsistent errors who, although not meeting all the criteria for diagnosis of DVD (developmental verbal dyspraxia) have a deficit in motor planning." Due to the limited current knowledge about sensorimotor speech control development, the suggested motor nature of these mentioned speech disorders cannot presently be specified satisfactorily. As result, differential diagnosis is impeded and suspected motor deficits cannot be as specifically addressed in treatment, which eventually affects the cost and time-effectiveness of service delivery. It is known that "...cost-effective treatment necessitates the use of specific intervention approaches that target specific deficits." (Bradford & Dodd,1994:364).

Additionally, it is likely that because of insensitive assessment tools, possible accompanying subtle sensorimotor deficits may go undetected in even more types of child speech and language disorders e.g. in cases of cleft lip and/or palate, velopharyngeal insufficiency and even mild to severe hearing impairment. "Obvious deficits such as those that occur in neurological impaired children, may be easy to detect: however, we do not currently have the tools to assess more subtle deficits." (Smith et al.,1995:88). The limited amount of research on sensorimotor aspects of speech production development has resulted in a gap in traditional assessment batteries used with children with DSD, where usually no attempt is made to comprehensively address sensorimotor aspects of speech production. Tests of oral diadochokineses, and standard assessments of oral-motor structure and functioning (in speech and non-speech tasks), are usually the only methods of evaluation mentioned under the umbrella-heading of 'speech motor assessment' in children (e.g. Lowe,1994; Creaghead, Newman & Secord,1989; Crary,1993). In addition, limited standard assessment guidelines are available for these procedures.

Such a narrow focus of assessment regarding speech motor development reflects little awareness of the complexity of speech as a fine sensorimotor skill and the different control processes involved in its production. Hall et al. (1993) stressed that assessment batteries addressing DSD should be sensitive to speech production and in particular to the performance of the speech mechanism during speech acts. Unfortunately, assessment batteries have only met such criteria to a very limited extent, mostly due to the small amount of normal speech motor developmental data on which such assessments can be based. "As clinicians we know that the utility of a diagnostic test depends on the existence of a normative database for the age range of interest." (Smith et al.,1995:88). Increased knowledge about speech motor development in normal children is thus crucial. It may assist in differential diagnosis by widening the focus of assessment and providing information that may help identify the underlying nature of various developmental speech disorders. Eventually such information will thus be beneficial to the development of more specific and subsequently more effective diagnostic and therapeutic techniques in DSD.

Expanded knowledge regarding sensorimotor speech control development will also contribute to a better understanding of both normal and deviant processes of adult sensorimotor speech control. Although a great amount of information exists regarding normal adult sensorimotor speech processes, recent literature in the field of acquired speech and language disorders called for a renewed focus on sensorimotor aspects of speech production (e.g. McNeil,1997). Some authors believe that assumptions underlying acquired neurogenic speech and language disorders need to be reconsidered by particularly focusing attention on motor aspects of speech production (McNeil & Kent,1990; McNeil,1997). In addition, there is a growing need to specify the nature of normal sensorimotor speech processes such as speech motor planning, programming and execution more clearly (Van der Merwe,1997). As in the case of children, the exact nature of possible sensorimotor speech problems in adults can presently only be specified to a limited extent. Developmental information regarding sensorimotor speech control processes may contribute to the understanding of mature speech production, resulting in the expansion and refinement of normal models of speech production (Smith,1978; Smith,1992). Ultimately such improved models of speech production will lead to the establishment of a more adequate basis for the evaluation and treatment of acquired speech and language disorders.

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In spite of the apparent need for and the clinical benefits of comprehensive normative information of speech motor development, such information is currently limited and incomplete. As recently as 1995, Smith et al. (1995:88) noted that "Work is just beginning in the task of generating a normative database for speech motor processes.". Through the years bulks of information have been accumulated regarding linguistic aspects of speech development such as semantics, syntax and grammar. The traditional focus in studies of speech development has been on the acquisition of phonological patterns or contrasting sound units (i.e. phonological development) and how these change over time (Hewlett,1990). In the past, the development of speech motor processes has thus mostly been inferred from linguistic approaches such as linguistic, phonetic and phonologic analysis (Sharkey & Folkins,1985; Smith & Goffman,1998), or perceptual approaches such as descriptions of intelligibility, quality, fluency and prosody (Kent,1997). Less research has been conducted about the phonetic aspects of speech production i.e. focussing on different aspects of sound acquisition and production (Hewlett,1990), and even less about the capabilities and constraints of the developing motor systems for speech (Kent,1981; Smith et al.,1995). The need for specifying possible accompanying and/or underlying speech motor deficits in a variety of both child and acquired speech and language disorders, thus demands a shift in attention from linguistic aspects to sensorimotor aspects of speech production in both research and assessment.

Some studies regarding sensorimotor aspects of speech development have been conducted through the years (e.g. Hawkins,1973; Kewley-Port & Preston,1974; DiSimoni,1974:a;b;c; Menyuk & Klatt,1975; Tingley & Allen,1975; Gilbert,1977; Zlatin & Koenigsknecht,1976; Smith,1978; Hawkins,1973;1979; Kent & Forner,1980; Macken & Barton,1980; Bond & Korte,1983:a & b; Smith, Sugarman & Long,1983; Rimac & Smith,1984; Sharkey & Folkins,1985; Chermak & Schneiderman,1986; Smith,1992; Goodell & Studdert-Kennedy, 1993; Kuijpers,1993; Smith,1994; Nittrouer,1993;1995; Smith,1995; Stathopoulos,1995; Moore & Ruark,1996; Ruark & Moore,1997; Smith & Goffman,1998; Smith & Kenney,1998). However, these studies are so diverse in terms of theoretical orientation, the aspects of speech motor development they focused on, and general methods followed (e.g. differences in language, age, gender, statistical analysis, material, and instrumentation used), that comparison and clinical applicability of results are very limited. Most existing studies of speech motor development are generally also characterized by a small number of subjects, which diminishes the representativeness of findings.

Some yet unresolved practical and instrumental factors have played a major hindering and restrictive role in previous research attempts of speech motor development, and still continue to be influential. It is clear that in order to establish a normative database of sensorimotor speech control development, researchers have to use methods that indeed address sensorimotor aspects of speech production. Part of such an approach generally implies the usage of recording and instrumental analysis procedures that may address the sensorimotor aspects of speech acquisition more directly, such as acoustic analysis, electromyography, aerodynamic measurement (e.g. with a pneumotactograph), kinematic measurements (e.g. palatometry, glossometry, cineradiography, nasendescopy, chest-wall magnetometry), and speech imaging (e.g. video-fluorography, ultrasound, computarized tomogrophy). Although each of these measurements has its own strengths and limitations, it is obvious that they can be used to complement each other and that their implementation will provide a more thorough and accurate understanding of various aspects of speech motor development (Smith,1995).

However, practical application of most of these instruments with children is easier said than done. For example, except for acoustic measurement, all of these physiological measurement instruments require that some kind of apparatus be worn (e.g. bead or disk electrodes, headband, pseudo-palate, magnetic coils) on the head, face, body, and/or in the mouth. This expects high levels of tolerance and co-operation from children. Moore and Ruark (1996:1035) aptly stated that "Very young children are difficult to study, which make the choice of method even more difficult because practical considerations will take priority over the theoretical ones.". Secondly, although the usage of these measurement instruments may provide valuable results regarding the development of sensorimotor speech control, they require a high level of expertise to ensure reliable analysis and interpretation. Additionally, such procedures are not yet

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readily available and require very expensive apparatus. Fortunately, speech scientists such as Ruark and Moore (1997) have become increasingly more interested and dedicated in solving the problems of physiological recordings in infants and young children. Hopefully in the near future more such efforts, together with technological advances will lead to more 'child-friendly' and cost-effective applications of these instruments, which may result in an increased number of studies on speech motor development. Until then, researchers are obliged to optimally utilize whatever forms of instrumentation are available in their specific circumstances. A combination of instrumental and non-instrumental analysis procedures will be used in this study. The less sophisticated method of acoustic analysis will be used as instrumental analysis procedure, since it is non-invasive, requires only a basic level of co-operation from the subjects, and can provide valuable information about sensorimotor speech control aspects such as segmental duration and inter-articulator synchronization (measured as voice onset time). Regardless of the type of instrumentation used to study speech motor development, it is essential that methods and especially research aims are based on a solid theoretical understanding of the nature of speech as a sensorimotor skill. With clear theoretical underpinnings even simplistic research methods can provide valuable information about sensorimotor aspects of speech development in the absence of highly sophisticated instrumentation.

Speech can be regarded as a fine sensorimotor skill, requiring precise timing and amplitude of activity and skilled movements in many different muscles (Borden & Harris,1980; Netsell,1982; Smith & Goffman,1998; Van der Merwe,1997). Speech is thus learned in accordance with laws governing the acquisition of any other motor skill, although the unique relationship between speech and other linguistic and non-linguistic systems implies that it also possesses unique characteristics (Hawkins,1984). As a fine sensorimotor skill, speech consists of skilled movements with some inherent characteristics that can be used to guide research and the development of assessment and treatment tools. Bruner (1973:5) described a skilled movement as involving the "....construction of serially ordered, constituent acts whose performance is modified towards less variability, more anticipation, and greater economy by benefit of feedforward, feedback and knowledge of results.". As a fine sensorimotor skill speech is "goal-directed", "afferent guided" and "....meets the general requirements of a fine motor skill viz., it (1) is performed with accuracy and speed, (2) uses knowledge of results, (3) is improved by practice, (4) demonstrates motor flexibility in achieving goals and (5) relegates all of this to automatic control, where 'consciousness' is freed from the details of action plans." (Netsell,1982:250). Since speech is goal-directed (Connolly,1977; Gracco,1990; Van der Merwe,1997), the identification and specification of possible speech motor goals and different aspects of their sensorimotor control development need to be central in studies of children's speech motor development. Research may thus focus on aspects of speech motor control such as timing, sequencing, coordination, accuracy, speed, variability, flexibility, anticipation and automatism of speech movements and how the characteristics and control of these aspects change with maturation.

The basic characteristics of speech as a fine motor skill have even more guiding and organizing potential when integrated in a theoretical framework or model of speech production. The need to work from a sound theoretical framework has long been proclaimed by various speech-language pathologists working in the field of adult neurogenic speech disorders, such as Marquardt and Sussman (1984), Van der Merwe (1986), Kent and McNeil (1987) and McNeil and Kent (1990). Similarly, Grunwell (1990) and Hewlett (1990) have also stressed the need for theoretical frameworks of speech production in which to present and address speech and DSD. Since normal speech motor development is still an evolving field of research, most of the indications we currently have about the process are still only hypotheses (Netsell,1986; Smith et al.,1995). Unfortunately, when reviewing research about speech motor development, one finds very little theoretical reference to the sensorimotor speech production process, such as the specific stage of speech production that is addressed, or definitions of terminology used. Such unnecessary "...stabs in the dark..." (Marquardt & Sussman,1984:11) can't be afforded. A theoretical framework of speech production, based on the characteristics of speech as a fine sensorimotor skill, can be effective in guiding and organizing hypotheses and the formulation of research aims. Further, such a framework may also assist in establishing uniform terminology in studies of sensorimotor speech development. It is likely that the

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small amount of focus on sensorimotor aspects of speech development may have partially been caused by the very confusing usage of linguistic terminology since the early 70's. Most of the time experts failed to make a clear distinction between terminology such as phonetic, phonologic and motor development of speech production. In order to improve understanding of available data and to avoid future confusion, researchers have to establish terminology clearly.

Van Der Merwe (1997) proposed a theoretical framework of sensorimotor speech control that possesses application value in the study of speech motor development. Although the model refers to mature (adult) speech production, it is still applicable, since adult speech production represents the end point of the speech developing continuum and as such reflects the "...elegance to which the developing system aspires and can be compared." (Netsell,1986:3). This framework portrays the transformation of the speech code from one form to another as seen from a brain behavior perspective. It is unique in the sense that it represents a paradigm shift from the traditional three stage speech production model consisting of linguistic encoding, programming and execution (Itoh & Sasanuma,1984) to one of four stages, based on current neurophysiological data on sensorimotor control (Van der Merwe,1997). "The proposed framework postulates that linguistic-symbolic planning should be differentiated from phases in sensorimotor control and that sensorimotor control of speech movements comprises planning, programming and execution phases." (Van der Merwe,1997:3). Van der Merwe (1997) stated that in adult speech control research, the true nature of motor planning of speech movements is not adequately contemplated and usually not differentiated from phonological planning. Similarly, it is found that this distinction between linguistic and motor processes in speech production is also not always clearly established in the majority of studies about sensorimotor speech development. This diminishes the clinical and research applicability of results, since some researchers use linguistic terms and refer to linguistic processes while their research actually addresses sensorimotor control or vice versa. Van der Merwe (1997:3) stated that "A clear differentiation among these processes or phases is necessary to comprehensively define the different sensorimotor speech disorders.". Such a distinction will also contribute to determine the underlying nature of suggested motor control problems in some developmental speech disorders.

As described before, several researchers have mentioned the possibility of a motor control component in some cases of developmental speech disorders (e.g. DAS and DPD), which calls for a shift in focus from linguistic to motor aspects of speech production. The framework of Van der Merwe (1997) thus fits the clinical need to focus on sensorimotor aspects of speech production and development. The framework's application value to studies of speech motor development is further enhanced by the fact that it specifies hypothetical motor aspects involved in every stage of sensorimotor control, which can be the focus of investigation in research. For example, Van der Merwe (1997) hypothesized that during the planning phase of sensorimotor control of articulated speech, a gradual transformation of symbolic units (phonemes) to a code that can be handled by a motor system has to take place. "Motor planning entails formulating the strategy of action by specifying motor goals." (Van der Merwe,1997:9), and these motor goals "...can be found in the spatial and temporal specifications of movements for sound production." (Van der Merwe,1997:11). These planned strategies for achieving the different motor goals then have to be "...converted into motor programs or tactics." (Van der Merwe,1997:13). According to Van der Merwe (1997:16) sensorimotor speech programming "....entails the selection and sequencing of motor programs of the muscles of the articulators....and specification of the muscle-specific programs in terms of spatiotemporal and force dimensions such as muscle tone, rate, direction and range of movements." (Van der Merwe,1997:16). These plans and programs are then "...finally transformed into non-learned automatic (reflex) motor adjustments." (Van der Merwe,1997:16). Existing studies of speech motor development relate their methods and discussions of results only to a very limited extent to possible sensorimotor control processes, and how spatial and temporal aspects (goals) of speech movements are planned, programmed and executed. In the process of gaining systematical insight in the characteristics and development of sensorimotor aspects of speech production, this framework can act as "...a simple map to guide our quest..." (Van der Merwe,1997:19), since it specifies possible events that take place during the process of sensorimotor control, which

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can be the focus of study. Considering the confusing current clinical and research scenario, this is certainly a much needed "map".

Based on the discussed clinical needs for more extensive normative data regarding speech motor development, this study aims to collect a variety of basic normative information regarding normal, Afrikaans-speaking children's speech motor development in the age range four to seven years. Diagnostically speaking this is an important age range, since a high number of children are referred for persistent DSD during these pre-school years. Due to practical difficulties of having children this young co-operate in a controlled research setting, the invasiveness and high cost of most instrumental procedures used in the study of speech motor development, the diversity in methods of existing studies, and a lack of theoretical focus on the sensorimotor control processes involved in speech production, limited information about normal children's speech motor skills in this age range is currently available. This impedes differential diagnosis, explanation of the underlying nature of some developmental speech disorders, as well as the formulation of more specific treatment plans in DSD.

The study will firstly focus on collecting normative information about what can be referred to as traditional aspects of evaluation usually found under the heading 'speech motor evaluation' of DSD. This includes the production of *isolated* and *sequenced non-speech oral movements*, *non-speech oral diadochokinesis* and *speech diadochokinesis* tasks. Due to the current clinical use of these types of assessment and the potential information it may provide regarding basic aspects of sensorimotor speech development (e.g. timing, sequencing and coordination of speech movements), they are central to a study of speech motor development. However, in view of the lack of comprehensive assessment guidelines in these areas, traditional assessment will be expanded by the compilation and application of rating scales, that can be used to rate and describe performance on these tasks. Improved assessment and rating guidelines in these areas may result in more detailed descriptions of children's performance in clinical settings, which can eventually benefit differential diagnosis of DSD.

Secondly, the traditional method of assessing speech motor development will be expanded by focusing on *additional* aspects of sensorimotor speech control as outlined by Van der Merwe (1997). If we want to specify the possible motor control aspects involved in developmental speech disorders such as DAS, or want to identify subtle speech motor deficits in other developmental speech disorders (e.g. DPD or stuttering), information about the nature of normal speaking children's sensorimotor speech skills is a crucial starting point. Most of these additional aspects of sensorimotor speech control will be analyzed in this study by using *acoustic analysis,* but the test battery will also be compiled with some extent of clinical applicability. Assessment will center around aspects such as initial and final *cluster production* and the nature of *word syllable structure* in spontaneous speech (i.e. length and type of consonant-vowel combinations), both of which assess basic aspects of consecutive speech motor goal planning and sequencing. Further, *timing* aspects of speech production (e.g. characteristics of first-vowel duration), *variability* of timing aspects (e.g. first-vowel duration in repeated utterances), planning of *inter-articulator synchronization* (e.g. as measured in voice onset time), as well as if and how children adapt *timing* aspects (e.g. first-syllable duration) to increasingly more complex contexts (e.g. words of increasing length) will be assessed. With such a referential database of a wide variety of aspects of speech motor development established, it is then planned to apply the same method in a later study to a group of children with developmental speech disorders (e.g. DVD and DAS). Since sensorimotor aspects and not linguistic aspects of speech production are the focus of this study, the data will be cross-linguistically applicable to some extent.

From the discussed theoretical and practical issues it is obvious that the study of sensorimotor speech control development is a complex field, encompassing several challenges. "It's an area ripe for research and rich with intriguing questions." (Smith et al.,1995). We find ourselves merely at the beginning of uncovering the different facets of speech motor control and its development. It is believed that research efforts with carefully constructed methods and based on solid theoretical underpinnings will contribute to this uncovering process. In time, the nature of speech motor control problems in developmental speech disorders may be specified more comprehensively and more adequately.

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1.2. DEFINITION OF TERMINOLOGY

Key concepts used in this study are defined as follows:

1.2.1. SPEECH

Speech is the "...expression of ideas and thoughts by means of articulate vocal sounds, or the faculty of thus expressing ideas and thoughts." (Random House Webster's Unabridged Dictionary,1998:1833). A more focused definition is that "Speech is the acoustic representation of language, that results from highly coordinated movement sequences produced by the actions of the speech mechanism." (Hodge,1993:128). Further, speech production is a highly precise and practiced motor skill that requires the coordination of sensory information with muscular responses and the organization of movements in space and time to produce actions directed at achieving a goal (Connolly,1981). "Speech is produced by the contraction of the muscles of the speech mechanism which include the muscles of the lips, jaws, tongue, palate, pharynx and larynx as well as the muscles of respiration." (Murdoch,1990:2). "Speaking is a complex action involving a number of levels of organization and representative processes." (Gracco,1990:3).

1.2.2. MOTOR AND/OR SENSORIMOTOR

Generally the term 'motor' refer to "...the process of conveying an impulse that results or tend to result in motion....or involving muscular movement." (Random House Webster's Unabridged Dictionary,1998;1255), or relates to muscular movement or the nerves activating it (The Concise Oxford Dictionary of Current English,1995). "Those nerve fibers that carry impulses from the central nervous system to the effector organs.....are called *efferent* or *motor* fibers." (Murdoch,1990:29). "*Afferent* or *sensory* nerve fibers carry nerve impulses arising from the stimulation of sensory receptors (e.g. touch receptors) towards the central nervous system." (Murdoch,1990:29). Brooks (1986:39) stated that "Sensorimotor integration is the key to motor control.". Although the "...exact

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YUNIBESITHI YA PRETORIA

nature of sensorimotor interface..." (Van der Merwe,1997:6) during phases of speech production is not yet known, it is "...evident that sensory information is an integral part of speech motor control." (Van der Merwe,1997:6). Feedback and feedforward information is probably utilized "...in a plastic and generative manner depending on task demands or context of motor performance." (Van der Merwe,1997:5).

Sensorimotor speech control can thus be defined as "...the *motor-afferent* mechanism that direct and regulate speech movements." (Netsell,1982:247). For the purpose of this study, the terms *sensorimotor* and *motor* will be used interchangeably, essentially referring to the same integrated process of speech production. However, the *focus* of the study, will be on the characteristics of *motor (efferent) control* processes involved in speech production.

1.2.3. DEVELOPMENT

Development refers to the act or process of developing, thus suggesting some kind of growth, progress or advancement (Random House Webster's Unabridged Dictionary,1998). More specifically development implies a "..continuous process of change, leading to a state of organized and specialized functional capacity; that is, a state wherein an intended role can be fully carried out, and may occur in the form of growth, maturation, or both simultaneously." (Haywood in Hodge,1993;128). In this study the word *development* thus refer to the *process* by which children eventually acquire adult-like speech.

1.3. CHAPTER LAYOUT

In *Chapter Two* a theoretical basis for the study of speech motor development will be established. The basic foundations of motor skills, terminology like motor goals, motor programs and motor plans, characteristics of speech as fine sensorimotor skill and the process of sensorimotor control as hypothesized by Van der Merwe (1997) will be presented. Information about the basic variant and invariant temporal and spatial aspects of sensorimotor speech control will also be reviewed. Secondly, research findings about different aspects of sensorimotor speech control development and relevant issues surrounding its research will be summarized. These theoretical underpinnings and overview of what is currently known about speech motor development and the research issues surrounding it, will provide an information basis from which the method of this study can be planned and results be integrated and compared with.

In *Chapter Three* the study's method will be described, with reference to aims, procedure for subject selection, selection criteria, measurement instruments and apparatus, research design, compilation of the assessment battery, data collection procedures, data analysis procedures and statistical analysis of data.

In *Chapter Four* the results for the different sub-aims will be described and discussed. *Chapter Five* will consist of an evaluation of the study, a summary of findings and implications of findings, a conclusive discussion and finally, recommendations for future research.

1.4. SUMMARY

In this chapter the clinical need for normative data on speech motor development was outlined, with reference to different child and acquired speech disorders. Theoretical and practical issues involved in the study of speech motor development were discussed. The necessity for shifting attention from linguistic to sensorimotor aspects of speech production, and the importance of focussing research on the characteristics of speech as a fine sensorimotor skill were emphasized. The value of using a hypothetical theoretical framework of the speech production process as guidance for constructing research methods, defining terminology and organizing research data was outlined. The main objectives of this study in terms of sensorimotor speech control development were then briefly sketched, based on the theoretical framework of Van der Merwe (1997).

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CHAPTER 2

SPEECH AS SENSORIMOTOR SKILL AND ITS DEVELOPMENT

2.1. INTRODUCTION

The development of sensorimotor speech control is a long and gradual process, starting at birth and proceeding into early adolescence (Netsell,1986). Various component processes such as perception, cognition, central nervous system maturation, neuromuscular and skeletal growth, as well as refinement of fine-force and spatial-temporal control over muscular structures contribute to speech motor development (Hodge,1993). The general premise of speech motor development is thus that "...speech is a motor skill learned in *interaction* with developing cognitive and linguistic sophistication and *subject to constraints* on perception as well as on production." (Hawkins,1984:355).

In this chapter a *theoretical basis* for the study of speech motor development will firstly be established by a brief outline of the very basic foundations of *motor skills*, a discussion of terminology like motor *goals*, motor *programs* and motor *plans*, a description of the characteristics of speech as a fine-motor skill, and the process of *sensorimotor speech control* as hypothesized by Van der Merwe (1997). This will be followed by information about the basic *variant* and *invariant* temporal and spatial aspects of sensorimotor speech control. These theoretical underpinnings play an important organizing role in establishing terminology, selecting and formulating research aims, and in providing a framework of interpretation of the results of this study.

The second part of this chapter will provide an overview of *existing knowledge* regarding sensorimotor speech development and some related *neurobiological* and *physiological* data. Speech motor development will be described in terms of possible *phases* of acquisition identified between *infancy* and *two years* of age.

Secondly, speech motor development after two years of age will be summarized, based on an assortment of diverse studies that have investigated different temporal and spatial aspects of sensorimotor speech control such as voice onset time (VOT), speaking rate, word and segmental duration, variability in children's speech, coordination and coarticulation. The relationship of speech to other oral-motor (non-speech) behaviors will also be reviewed, since it is a somewhat controversial issue that needs to be considered in research of speech motor development. This overview of what is currently known about speech motor development and the problems and issues surrounding it, will provide an information basis from which the method of this study can be established and results discussed and explained.

2.2. COMPONENTS OF MOTOR SYSTEMS

Although speech motor systems are special in the sense that they convey language, they nonetheless operate according to principles fundamentally similar to those that underlie all movement production (Hawkins,1984; Smith et al.,1995). The following 'back-to-basics' review of the components of motor systems will establish a foundation for the understanding of speech as a fine-motor skill, and is crucial for developing insight into theories and research findings of sensorimotor speech control development.

2.2.1. MOTONEURONS

"The physical act of speaking can be viewed as a series of transformations beginning with a set of neural effector commands that control more than 100 muscle contractions." (Netsell,1986:2). These muscle contractions are controlled by nerve impulses that descend from the "...motor areas of the brain to the level of the brainstem and spinal cord and then pass out to the muscles of the speech mechanism..." (Murdoch,1990:2). The ends of this pathway out to the muscles are the motoneuron pools. "A motoneuron pool is a group of neurons that innervates a single muscle. Motoneuron pools are organized in columns within the brain stem (for craniofacial muscles) or the spinal cord (for chest wall and limb muscles)..... Each motoneuron of the pool has a long axon that travels out to the muscle and connects to several......muscle fibers. If a motoneuron fires an action potential, every muscle it is connected with also fires. The muscle fiber firing starts the contraction process of the muscle." (Smith et al.,1995:89). This constitutes the "final common pathway" (Sherrington's familiar term), because the motor neuron is the only pathway to a muscle. Any motor activity whether it is chewing, running or speaking depends on the proper timing and amplitude of activity of muscles. "Motoneuron pools, therefore, are critical control points in the motor system." (Smith et al.,1995:89).

Inputs to the motoneuron pool, which is a combination of many synaptic 'driving' signals that may be either excitatory or inhibitory, determine whether a motoneuron pool and the muscle it innervates, becomes active. Major sources of input (control signals) to a motoneuron pool includes the sensorimotor cortex, the basal ganglia, the cerebellum, the brain stem, interneuron pools and reflexes (Smith et al.,1995). Many different reflexes arising from sensory receptors in the skin, muscles and joints affect the activity level of the motoneuron pool. Interneuron pools integrate information from many different sites and process this information before influencing the activity level of the motoneuron pool, while cortically and brainstem originated signals operate on motoneuron pools directly and indirectly, through interneuron pools (Smith et. al.,1995).

2.2.2. TYPES OF MOVEMENTS AND THEIR NEURAL CONTROL

Motor systems are interactive and hierarchical which means there are many different levels of control and that these levels interact (Brooks,1986; Gracco,1990; Jakobson & Goodale,1991). "It is convenient to think of classes of movements based on their major locus of neural control." (Smith et al.,1995:90). Three categories that can be described are reflex, automatic and skilled actions.

Firstly, *reflexes* can be described as "....relatively stereotyped responses to sensory stimuli. In reflex muscle contractions, the major locus of control is in the sensory receptors that detect a stimulus and the low-level (spinal cord or brain stem) circuitry that produces the response." (Smith et al.,1995:90). Relative *automatic actions* may include "...respiration, mastication, swallowing and locomotion." (Smith et al,1995:90). The major locus of neural control for each of these actions may be a central pattern generator (CPG) which is a neural network that can produce the basic features of the motor behavior. It is speculated that humans might have a CPG for breathing which is thought to be a network of neurons in the brainstem, which produces the basic alternating pattern of inspiration and expiration (Smith et al.,1995). CPG's might further interact with other sources of control such as higher level centers and lower level circuits, such as reflexes (Smith et al.,1995).

Skilled actions refer to "...those motor behaviors that are learned and for which a major locus of neural control is the cortex. Speaking, hitting a tennis ball and playing a piano are all skilled actions. It is likely that the cortex generates command signals that drive interneuron and motoneuron pools to produce the smooth, sequential, coordinated movements necessary for skilled actions." (Smith et al,1995:91). Through learning, these command signals, which go by many names such as motor templates, central patterns, motor plans and motor programs, are refined and stored to be activated when appropriate. It should be noted that both developmental and adult speech motor control research are characterized by variant usage of these terms. Investigators appear to have very individual definitions and/or theoretical orientations about what these stored signals should be called and what their nature is (see following discussion). "The centers in the nervous system that provide the primary control signals for skilled actions must interact with, and influence CPG and reflex circuitry." (Smith et al.,1995:91).

2.2.3. MOTOR GOALS, MOTOR PROGRAMS AND MOTOR PLANS

Most neurophysiologists recognize that the overall *motor control process* involves several phases or hierarchical levels of organization which is generally

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identified as planning, programming and execution (Schmidt,1978; Brooks, 1986; Gracco,1990; Jakobson & Goodale,1991). Similarly, sensorimotor speech control can thus be argued to consist of motor planning, motor programming and execution phases (Van der Merwe,1997). Such a view implicates that the *motor planning phase* results in *motor* *plans*, while the *motor programming* phase results in m*otor* *programs*. The *motor goals* involved in speech sound production are thus converted to *motor plans*, which again have to be converted to *motor programs*, which are then finally *executed*. Although the exact nature of these goals, plans and programs is still not clear (Smith et al.,1995), it is important that we recognize and identify them as independently existing, non-linguistic phenomena.

The very confusing and interchangeable current usage of terminology is clearly illustrated in the following excerpt of Hewlett (1990:29) who presented a model of speech production that "....specifies a number of different levels in the speech production process." and "....provides a useful basis for discussing the distinctions among the different types of (developmental) speech disorders from a *linguistic* point of view." Hewlett (1990:30-31) for example, hypothesized that "....the Motor Programmer receives the auditory-perceptual representation of a word and attempts to devise a motor plan for its production...", and "When a motor plan for a perceptual target has been devised the information is relayed into the Motor Processing Component. The task of the Motor Processing component is to assemble the motor plan of the sequence of gestures involved in pronouncing the word, and determine the precise value of the articulatory parameters involved." *(emphasis provided).* Van der Merwe's (1997) differentiation between and defining of these phenomena provide a much needed terminology basis that is important for avoiding confusion when interpreting existing research findings and planning research methods.

2.2.3.1. Motor goals

"Motor planning is goal-orientated, and *motor goals* for speech production can be found in the temporal and spatial specifications of movements for sound production." (Van der Merwe,1997:11). The sounds in each language has their own specifications (features) which determines the "....invariant core motor plan with spatial (place and manner of articulation) and temporal specifications for each sound. The specifications of these movements constitute the motor goals." (Van der Merwe,1997:11). Motor goals are invariant and thus the *targets* or object of sensorimotor speech planning. The following possible motor goals (although not conclusive) called articulatory parameters, which have to be specified in speech production, have been identified by Ladefoged (1980). Movements of the *jaw* for example, (e.g. jaw depression) can also be added to this list:

-*tongue*: front raising, back raising, tip raising, tip advancing, lateral tongue contraction, tongue bunching

-*lips*: lip width, lip protrusion, lip height

-*velum*: velic opening and closing

-*pharynx*: pharynx width

-*larynx*: larynx lowering, glottal aperture (opening), phonation tension

-*chest wall*: lung volume decrement

2.2.3.2. <u>Motor plans</u>

A *<u>motor plan</u>* is necessary to *guide* speech movements (Van der Merwe,1997). The invariant core features of a sound determine the invariant *core* motor plan with spatial (place and manner of articulation) and temporal specifications for each sound. Van der Merwe (1997) suggested that this core motor plan is attained during speech development and that the motor specifications and sensory model are stored in the sensorimotor memory. The core-motor plan for each sound in the utterance are then successively recalled during the motor planning stage of speech production. However, in the realization of speech (i.e. on the articulatory level) we know that speech movements are variant and context dependent (Borden & Harris,1980; MacNeilage,1980; Perkell & Klatt,1986; Van der Merwe,1997). The core-motor plan thus has to be adapted to the context of the planned unit (e.g. sound context, rate of production, utterance length, motor complexity of the utterance) (Van der Merwe,1997). Motor plans

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are *articulator-specific* and constitute strategies and specifications of *how* to reach the motor goals within a particular context of production, while keeping these movement adaptations within limits of equivalence to ensure that the critical acoustic configuration is reached (Van der Merwe,1997).

2.2.3.3. Motor programs

During sensorimotor programming, strategies (the motor plans) are converted to motor programs (Van der Merwe,1997). Marsden (1984:128) defined the *motor program* as follows: "The motor program is a set of commands that are structured before a movement sequence begins which can be delivered without reference to external feedback.". The motor program specifies muscle tone, movement direction, force, range, rate and mechanical stiffness of the joints (Brooks,1986). The timing and amount of muscle contractions in agonists, antagonists, synergists and postural fixators need to be specified prior to movement onset (Marsden,1984). Motor programs are *muscle-specific* in terms of spatio-temporal and force dimensions such as muscle tone, rate, direction and range of movements (Van der Merwe,1997). During the final execution phase of sensorimotor control, motor programs are translated into muscle activity.

2.3. ADULT SENSORIMOTOR SPEECH CONTROL

In a discussion of sensorimotor speech control development it is necessary to include information about what is known about adult sensorimotor speech control, even though "All the data on adult speech motor control are far from being in." (Netsell,1986:3). Adult sensorimotor speech control is of interest when considering sensorimotor speech acquisition, because "…it represents the end point of the developmental continuum and, as such, reflects the elegance to which the developing system aspires and can be compared." (Netsell,1986:3).

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2.3.1. SPEECH AS A FINE-SENSORIMOTOR SKILL

The characteristics of speech as a fine-sensorimotor skill can be summarized as follows:

-it is *goal-directed* (Connolly,1977; Gracco,1990) i.e. variant and invariant temporal and spatial features of speech movements (Van der Merwe,1997)

-as a motor control system it is *generative* and *plastic* in nature (Van der Merwe,1997)

-it is *afferent (sensory)-guided*, thus utilizes feedback and feed-forward information at multiple levels of speech processing (Van der Merwe,1997)

-it uses *knowledge* of results (Netsell,1982)

-it is improved by *practice* (Bruner,1973; Netsell,1982)

-its performance is modified towards *less variability*, more *anticipation* and greater *economy* (Bruner,1973)

-movements are performed with *accuracy* (Netsell,1982)

-movements are performed with *speed* (Netsell,1982)

-it reflects the ability to "...make finer and more varied *adjustments* of the vocal tract." (Gracco,1990:6)

-it demonstrates motor *flexibility* in achieving results (Netsell,1982)

-it relegates all of this to '*automatic*' control, where 'consciousness' is freed from the detail of action plans (Netsell,1982), thus speech movements are made in a *sub-conscious* manner (Netsell,1986)

-"...speech as motor control system include a control structure in which the smallest functional unit is the entire vocal tract." (Gracco,1990:7), reflecting sophisticated *coordination* and *inter-articulator synchronization*

-it is *context-sensitive*, movements are thus adapted to the context (MacNeilage, 1980; Van der Merwe,1997)

-movements are *sequentially organized* (Gracco,1990).

These characteristics need to be gradually acquired and refined during sensorimotor speech control development and have to be the focus of research. In order to compile a normative database regarding sensorimotor speech control, we thus need information about the development of aspects such as *variability* of

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speech movements, *speed* of articulation, *accuracy* and *precision* of production, *inter-articulator synchronization* (e.g. as reflected in voice onset time), *coordinating* ability, and *sequential organization* of speech movements for sounds in the child's mother tongue. We also need to determine how spatial and temporal specifications of speech movements are *adapted* to the *context* of production (e.g. sound context, rate of production, utterance length) and thus how 'flexible' the child's sensorimotor speech control system is. This study investigated some of these aspects. The following framework of sensorimotor speech control, hypothesized by Van der Merwe (1997) will illustrate how these characteristics are hypothetically realized during the process of adult speech production.

2.3.2. THE PROCESS OF SENSORIMOTOR SPEECH CONTROL

In Chapter One it has been established that in order to obtain information to specify suspected *motor control* components of some cases of developmental speech disorders more adequately, there need to be a *shift* in attention from *linguistic* to *sensorimotor* aspects of speech development in research. In addition, the diverse nature of existing studies of speech motor control development, the interchangeable usage of terminology, and the fact that most findings are still only hypothetically explained, call for the implementation of some kind of theoretical framework of the speech production process. In order to be applicable to a study of normal speech motor development, such a framework needs to differentiate clearly between *linguistic* and *sensorimotor* processes of speech production. It should include hypothetical descriptions of the process of sensorimotor speech control and specific aspects that need to be controlled. Further, such a model should have the potential to provide a theoretical background for defining terminology, interpreting and organizing existing data, planning research and integrating results.

Several models of adult speech production that can be considered for use as theoretical framework in this study, have been postulated through the years by

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researchers such as Liberman, Cooper, Shankweiler and Studdert-Kennedy (1967), MacNeilage (1970), Kent and Minifie (1977), Lindblom, Lubker and Gay (1979), Borden and Harris (1980), Mlcoch and Noll (1980), Bell-Berti and Harris (1981), Itoh and Sasanuma (1984), Nation and Aram (1984) and Kent (1990). These models are diverse in terms of aspects such as theoretical orientation, details provided regarding specific phases of speech production (e.g. processes or parameters that need to be controlled), the extent to which linguistic and sensorimotor processes of speech production are differentiated, what the unit of speech production (e.g. phoneme, syllable or target-based) is considered to be, and the extent to which neurophysiological data on sensorimotor speech control are incorporated in the model. Although many of these models possess aspects that can be applied to a study of normal speech motor development, no single one is developed to the extent needed to qualify for use as theoretical framework in this study. Generally, not all aspects of speech production are addressed, or not enough details are provided in terms of different aspects or parameters that need to be controlled. To the knowledge of the author, none of these models have been directly applied to normal children's speech production.

No models of speech production that specifically aim to conceptualize the speech production processes and sensorimotor speech control in normal children's speech, could be identified either. However, some interesting models of speech production, which have been specifically applied to children's speech exist in the field of developmental speech disorders. Three of these models that can be considered for usage as a theoretical framework in this study are those of Hewlett (1990), Crary (1993) and Dodd (1996). The basic aspects of these models are summarized in Table 2.1. It is concluded from this summary that these models also are not developed in enough detail to be used as theoretical framework of the speech production process for the purposes of this study.

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TABLE 2.1: SUMMARY OF RELEVANT MODELS OF CHILDREN'S SPEECH PRODUCTION

MODEL	SUMMARY OF ITS APPLICABILITY TO THIS STUDY
Hewlett (1990): *"A proposed model of phonological processing and phonetic production."* (Hewlett,1990:29). Main components: **Input Lexicon* **Output Lexicon* **Motor Programmer* **Motor Processing* (syllable level) **Motor Processing* (segmental level) **Motor Execution* **Vocal Tract* (shape/movements)	It does specify a number of different levels of the speech production process but do not clearly differentiate between linguistic and non-linguistic processes. It is confusing in terms of terminology used and the terminology is not well explained. The *terms motor plan* and *motor program* for example, appear to be used interchangeably, e.g. the author postulates that the motor *programmer* devises a motor *plan* (see Hewlett,1990:31-32). The model is not related to current neurophysiological data of speech motor control and thus does not recognize the fact that overall motor control processes involve several phases or hierarchical levels of organization, usually identified as planning, programming and execution (Jakobson & Goodale,1991; Brooks,1986).No details are supplied in terms of parameters that need to be controlled or processes involved in each of the different proposed levels of speech motor control. The overall focus is on phonological and linguistic aspects of speech production.
Crary (1993): *"A proposed motolinguistic model for developmental speech disorders."* (Crary (1993:59). * "...speech begins as a mental concept that becomes linguistically organized, is transformed into motor behavior, and is executed as movement." (Crary,1990:55) "Moto-linguistic functions are envisioned along the anterior-posterior dimension as a continuum from executive functions to planning functions." (Crary,1993:60).	Crary (1993:56) recognizes the fact that their is "...many potential information processing steps applicable to speech production, between the selection of targets and the execution of movement.". He also emphasizes the ideas of Brooks (1986) that "Motor behavior starts with a goal or idea, which is organized into a plan, coded into a specific motor program and executed." (Crary 1993: 54). Yet, in spite of his statements, these ideas are not fully incorporated in his approach. For example, he seems to regard "planning" as only a linguistic function in his model (one end of the continuum), and does not recognize *motor* planning clearly in his model. Only 'execution' is assigned a 'pure' motor function (as the other extreme end of his continuum). Thus, Crary (1993) does not apply the concept of sensorimotor speech control as a three-phase process, separate from linguistic-symbolic planning to his model. Further he postulates no details in terms of parameters that need to be controlled or processes involved during 'planning' and 'execution'. This model may have some application value in the field of DSD if further developed. However, in its current form, it is very difficult to apply to normal speech production, due to the lack of details and the seemingly non-hierarchical approach to speech production.
Dodd (1996): *"Model of the Speech Processing Chain."* (Dodd,1996:67) *-Perceptual analysis* (auditory and visual modalities) *-Non-linguistic knowledge* (culture), *Lexicon* (phonological representation), *Linguistic knowledge* (phonology, morphology, syntax, semantics, prosody, pragmatics) *-Realization rules* *-Phonological plan* (stored routines) *-Motor Speech Program, Phonetic Assembly and Program Implementation* *-Execution*	This model has potential to differentiate different levels of breakdown in the speech production process that may account for subgroups of DSD. However, although Dodd does differentiate between motor and non-motor speech processes to some extent, sensorimotor speech control is not viewed as a three-phase process. Dodd (1996) uses terms such as "phonological-*planning*" (Dodd, 1996:79), "phonetic-*programming*" (Dodd,1996:84), and "motor-*execution*" (Dodd,1996:88). Motor *planning* is thus not recognized as an essential part of speech production (i.e. as part of sensorimotor speech control) and the model only allows for linguistic (phonological) planning. Dodd (1996) does provide some description of expected *deviant* behavior on each level of the model, but unfortunately does not provide details of normal aspects to be controlled at each level. This model appears to be very similar to that of Itoh and Sasanuma (1984,) in the sense that it regards speech production as mostly a *three-stage* process.

A final model of speech production that can be considered is the four-level model of mature speech production recently proposed by Van der Merwe (1997). This model was found to best fit the requirements of this study. To the knowledge of the author this is the only framework that differentiates clearly between the *non-motor* (linguistic-symbolic planning) and *sensorimotor* control phases of speech production. "This proposal represents a paradigm shift from the traditional three-stage speech production model (Itoh & Sasanuma,1984) consisting of linguistic encoding, programming and execution to one of four stages based on current neurophysiological data on sensorimotor control." (Van der Merwe,1997:1). The model portrays the transformation of the speech code from one form to another, as seen from a brain behavior perspective. It also "...poses a novel view on the phases involved during the transformation and stresses the importance of sensorimotor interface." (Van der Merwe,1997:1). Van der Merwe (1997) presents sensorimotor speech control as consisting of three distinct processes (i.e. motor planning, motor programming and motor execution), based on current *neurophysiological* data. "The differentiation of the three motor levels is in accord with the motor hierarchy accepted by most neurophysiologists." (Van der Merwe,1997:8).

The unique characteristics of this framework provide a basis from which research aims can be defined (in terms of identifying possible processes involved in sensorimotor speech control), a test battery compiled and data organized and integrated. This model can also be used in future studies of speech motor development in DSD for example, since it has the potential to characterize pathological sensorimotor speech control to some extent. "The differentiation between levels or phases of linguistic-symbolic planning, motor planning, motor programming, and execution would suggest that a distinct disorder (or disorders) on each of these levels is conceivable." (Van der Merwe,1997:17).

The model will now be described in more detail. Since this study focuses on the motor aspects of speech production, neural structures involved in each phase of production and the sensory aspects of sensorimotor control will not be discussed (See Van der Merwe,1997, for a detailed discussion of these aspects). During

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

speech production, the "....intended message has to be changed from an abstract idea to meaningful language symbols, and then to a code amenable to a motor system." (Van der Merwe,1997:2). Although speech has to be "...viewed within the superordinate behavior of language..." (McNeil & Kent,1990:352), it is also essential to view it as a sensorimotor function of the human brain. "A motor plan (not an abstract linguistic choice of a phoneme to be uttered), is necessary to guide speech movements." (Van der Merwe,1997:3). Sensorimotor control comprises planning, programming and execution phases. Linguistic-symbolic planning has to be differentiated from phases in sensorimotor control, since it is "non-motor" (Van der Merwe,1997:9) in nature. The three phases of sensorimotor control as presented by Van der Merwe (1997) are summarized in Table 2.2.

Apart from providing an organizational and planning framework for research, Van der Merwe's (1997) framework may also help to establish uniform terminology in studies of sensorimotor speech development. The limited attention given to developmental aspects of sensorimotor speech production may partially have been the result of the very confusing usage of linguistic terminology since the early 70's. Most of the time experts failed to make a clear distinction between motor and non-motor aspects of speech production development, mainly using the term *phonetic development* in reference to sensorimotor aspects of speech development. Grunwell (1990:6) for example, listed *motor speech* skills as being "...articulatory and phonetic abilities...". In order to improve understanding of available data and to avoid future confusion, researchers have to differentiate very clearly between phonological, phonetic and sensorimotor control aspects of speech development.

Phonology "....is the sub-discipline of linguistics that focuses on speech sounds and sound patterns." (Lowe,1994:1) and is used to "...refer to the system of differences in speech sounds that convey meaning in languages." (Ohde & Sharf, 1992:1). Research about phonological development is thus directed at "...describing and explaining the development of the system of contrasting sound units as manifested in the child's speech output." (Hewlett,1990:15).

TABLE 2.2 : A SUMMARY OF THE PHASES OF SENSORIMOTOR SPEECH CONTROL HYPOTHESIZED BY VAN DER MERWE (1997)

PHASE	EVENTS
Motor Planning	-During the planning phase of the production of articulated speech a gradual *transformation* of symbolic units (phonemes) to a *code* that can be handled by a motor system has to take place. -*Motor planning entails formulating the strategy of action by specifying motor goals* -Planning is mediated by the "highest" level of the motor hierarchy. -"Motor planning is *goal-orientated*, and motor goals for speech production can be found in the *temporal and spatial specifications* of movements for sound production" (Van der Merwe,1997:11). (The phoneme within the context of the utterance is the unit of planning). The sounds (phonemes) in every language can be described in terms of place and manner of articulation. Each sound has its own specifications, and these core features can be considered as invariant. -The core features determine the *invariant core-motor plan* with spatial (place and manner of articulation) and temporal specifications for each sound. The specifications of movements constitute the *motor goals.* -The core motor plan is attained during speech development and the motor specifications and sensory model (what it feels and sounds like) are stored in the *sensorimotor memory.* While mastering the core-motor plan, proprioreceptive, tactile and auditory *feedback* is implemented. -The first step in motor planning is to *recall the core motor plans* of the sequence of phonological units (phonemes) from the sensorimotor memory. -Next, planning of the *consecutive movements* necessary to fulfill the spatial and temporal goals commences. The different motor goals for each phoneme are to be identified and the movements necessary to produce the different sounds in the planned unit are then sequentially organized. -Motor planning is *articulator-specific* (and not muscle-specific). Motor goals such as lip rounding, jaw depression, glottal closure or lifting of the tongue tip need to be specified. -*Interarticulator-synchronization* is to be planned for the production of a particular phoneme and at this stage coarticulation potential is created. -The core motor plan of the phoneme (and thus temporal and spatial movements) has to be adapted to the context of the planned unit. *Adaptation* of spatial specifications to the phonetic (sound) context and to the rate of production and adaptation of temporal specifications to segmental duration, coarticulation potential, and interarticulator-synchronization takes place. Movement adaptation has to be kept within certain limits of equivalence. Internal feedback of an efferent copy to the sensorimotor cortex is implemented to keep adaptation of the core plan within the limits of equivalence. "Knowledge of results" is therefore utilized. Adaptation of the core motor plan takes place before articulation of a particular phoneme is initiated as adaptation determines the innervation of specific structures at particular points in time. -Following the identification of motor goals in accordance with the necessary adaptations to the core plan, different *sub-routines* that constitute the *motor plan are specified.* Co-occurring and successive subroutines such as lip rounding and velar lifting are specified and *temporally organized.* -Systematic feedforward of *temporally arranged, structure-specific motor plan subroutines* to the motor programming system then occurs.
Motor Programming	-At the middle level of the motor hierarchy, *strategy is converted into motor programs or tactics.* Specific movement parameters are computed in the motor program

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TABLE 2.2 (-CONTINUED) : A SUMMARY OF THE PHASES OF SENSORIMOTOR SPEECH CONTROL HYPOTHESIZED BY VAN DER MERWE (1997)

PHASE	EVENTS
Motor Programming *(-continued)*	-Programs specify muscle tone, movement direction, force, range and rate as well as mechanical stiffness of the joints according to the requirements of the planned movement as it changes over time. -The timing and amount of muscle contraction in antagonists, synergists, and postural fixators need to be specified prior to movement onset. -Programming of speech movements entails the *selection and sequencing* of motor programs of the muscles of the articulators (including vocal folds), and *specification of muscle-specific programs* in terms of spatiotemporal and force dimensions (such as muscle tone, rate, direction and range of movements). -Updating of programs based on sensory feedback can occur. Repeated initiation and feedforward of co-occurring and successive motor programs have to be controlled.
Execution	-Finally, the "...hierarchy of plans and programs is *transformed into non-learned, automatic (reflex) motor adjustments*." (Van der Merwe,1997:17). -Successive specifications are relayed to the lower motor neuron centers that control joints and muscles through the 'final common path'. Programs are translated into activity of alpha and gamma motor neurons and reflexes that are under descending control of the middle level are modulated to meet the circumstances within which the movement occurs. -Thus, descending pathways carry tactical instructions to the lowest level, where they are coordinated and finally translated into *properly timed commands* for muscle movements.

According to Van der Merwe (1997:9) "Phonologic planning.....entails the selection and sequential combination of phonemes in accordance with the phonotactic rules of the language.". Phonological aspects of developmental speech production can thus be regarded as part of the *linguistic-symbolic planning phase* of speech production and *non-motor* in nature.

Phonetics is the "...study of the production and acoustic properties of speech sounds as elements of language. It involves the analysis, description and classification of sounds as they relate to each other." (Ohde & Sharf,1992:1). Phonetics is thus a *sub-discipline* apart from phonology, concerned with the characteristics of speech sounds. However, in theoretical discussions regarding DSD, the term *phonetic development* is often used as almost a synonym for *motor* aspects of speech production (e.g. Grunwell,1990; Howell & McCartney,1990). Hewlett (1990:24) stated that "Phonetic studies of children's speech include those who have investigated general aspects of speech motor control and those which have investigated production of particular sounds and sound contrasts.". Based on Van der Merwe's (1997) model, it can be speculated that the phonetic characteristics of speech sounds may constitute the spatial (place and manner) and temporal movement specifications, or *motor goals* that need to be planned, programmed and executed during sensorimotor speech control. As such, phonetic development can thus be considered only a small part of the overall process of *sensorimotor speech* control development, which clearly entails much more aspects than the acquirement of a knowledge base of speech sound characteristics (i.e. phonetic development).

2.3.3. INVARIANT AND VARIANT ASPECTS OF SPEECH PRODUCTION

Some knowledge about the invariant and variant characteristics of adult speech production has been acquired through the years, supplying further evidence of the complexity and sophisticated nature of speech production. This is important information, since it highlights the limits wherein speech motor control takes place, yet demonstrates the flexibility of the speech control system in handling a variety of influences in order to produce an acoustic goal within these constraints. Research about these influences on sensorimotor speech control can provide valuable information concerning underlying sensorimotor speech processes.

2.3.3.1. Invariant aspects of speech production

It is evident that some degree of invariance is central to speech production, since the acoustic end result has to contain certain information that makes a sound recognizable as a specific phoneme or allophone of that phoneme (Linell,1982). In order to reach this critical acoustic configuration (Lindblom et al.,1979), spatial and temporal adaptation of speech movements to the context has to be kept within certain limits of equivalence. "The spatial and temporal differences between certain sounds are in many cases minimal, and if these boundaries are violated, the sound will be perceived as being distorted or even substituted by another sound." (Van der Merwe,1997:12). Gracco and Abbs (1986) found evidence for some degree of invariance in speech movements. Their study of upper lip, lower lip and jaw kinematics during certain speech behaviors, showed evidence that "...speech motor actions are executed and planned presumably in terms of relative invariant combined multi-movement gestures." (Gracco & Abbs,1986:156).

The sounds (phonemes) in every language possess certain individual, invariant articulatory characteristics that can be described in terms of place and manner of articulation. These core features can be considered as invariant (Stevens & Blumstein,1981). Van der Merwe (1997:11) hypothesized that these core features of sounds "...determine the *invariant core-motor plan* with spatial (place and manner of articulation) and temporal specifications for each sound..." which is recalled during the planning phase of sensorimotor speech control. "The specifications of movements constitute the *motor goals."* (Van der Merwe,19978:11). The core motor plan might be attained during speech development and "...the motor specifications and sensory model (what it feels and sounds like)..." (Van der Merwe,1997:11) might be stored in the *sensorimotor memory* (Van der Merwe,1997). While mastering the core-motor plan, proprioreceptive, tactile and auditory *feedback* are implemented (Van der Merwe,1997).

2.3.3.2. Variant aspects of speech production

In spite of the fact that a certain degree of invariance is necessary in speech production in order to reach the acoustic end goal, another characteristic of speech that has important implications for research about speech motor development, is the fact that on an articulatory level, speech movements are "...*variant* and *context-dependant..."* (Van der Merwe,1997:11), and that the boundaries between discrete phonological units fade away (Perkell & Klatt,1986; MacNeilage & De Clerk,1969; Kent & Minifie,1977; Calvert,1980). The core motor plan of the phoneme has thus to be adapted to the context of the planned unit. Complex overlap of articulatory movements shows that temporal ordening

UNIVERSITEIT VAN PRETORIA
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of articulation events is not reconcilable with temporal ordening of more abstract units such as phonemes, syllables and words (Kent & Minifie,1977; Calvert,1980). Thus, speech "..appears to violate what can be called the linearity and invariant conditions." (Wanner, Teyler & Thompson,1977:6) and speech "..is a continuously changing acoustic stream produced by dynamic articulatory processes." (Borden & Harris,1980:124). Contextual influences may include aspects such as sound and phonological structure, voluntary versus involuntary (or automatic) speech, motor complexity of the utterance, length of the utterance, familiar versus unfamiliar utterances and rate of speech (Van der Merwe,1997). However, such a list may be incomplete, while the exact role of these contextual factors in the different phases of speech production have yet to be determined more comprehensively (Van der Merwe,1997). Research of the effect of some of these contextual factors on children's sensorimotor speech control may shed more light on the characteristics of the developing speech control system. One of the aims of this study for example, was to investigate how (and if) *word length* affected vowel duration in children's speech. The most important sources that may contribute to variant temporal and spatial aspects of speech movements will now be discussed.

2.3.3.2.1. Sources of variance in spatial aspects of speech movements

Variance in spatial movements may originate from sound (phonetic) influence processes such as *adaptation*, *assimilation*, and *coarticulation* (Borden & Harris,1980). "*Phonetic adaptations* are variations in the way in which articulators move and the extent to which cavities change shape, according to what phonemes are neighbors. Articulatory positions and cavity shapes for one phone determine the movements necessary to produce nearby phones and the results of adaptation are evident in acoustic, movement and EMG-data." (Borden & Harris,1980:124). For example, tongue-palate contact for the [k] in 'key' is often less back than for the [k] in 'caught' since the consonant is adapted to the vowel (Borden & Harris,1980). An extreme form of adaptation is called *assimilation*, where a phone may actually change to be more like its neighbors and one feature of a sound is thus extended to another (Borden & Harris,1980).

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

This influence can either be anticipation of the next sound (called *anticipatory / right-to-left assimilation*) or it can be *carryover* (left-to-right) assimilation where an ongoing feature is continued into the next sound (Borden & Harris,1980).

Another phonetic influence in speech production is coarticulation. Coarticulation is the temporal overlapping of movements for different sounds, thus where two articulators are moving at the same time for different phonemes (Kent & Minifie,1977; Netsell,1984). "This differs from adaptation (one articulator modifying its movements due to context), and from assimilation (actual sound change), although they are obviously related." (Borden & Harris,1980:127). X-ray studies showed evidence for coarticulation. Perkell (1969) for example, found patterns of coarticulation of the tongue and mandible in utterances such as [tɑt] vs. [nɑt]. The nasal initial consonant involves tongue movement, which frees the mandible to start moving (lowering) for the [ɑ] at the same time. When the initial consonant is a stop however, e.g. [t], the mandible waits until alveolar closure is obtained before lowering for vowel opening. Stops require high pressure behind the closure which nasals do not, and premature jaw lowering would thus threaten the loss of that pressure. Research showed that if an articulator is free to move, it often does (Borden & Harris,1980).

Coarticulation can actually be regarded as a form of both spatial and temporal variance. It is discussed under spatial variance, however, because on a manifested level, it implies that movements for a particular sound will vary according to the coarticulation potential of the utterance (Van der Merwe,1986). A phenomenon such as coarticulation proves that motor planning of speech takes place before its production (Van der Merwe,1986). All sound influences demonstrate that "..speech is not produced as beads are put on a string, one phone after another. The sounds overlap and flow into one continuously changing stream of sound, further bonded by slowly changing modifications overlaid upon it." (Borden & Harris,1980:128).

Motor equivalence is another important characteristic of speech movements that contributes to the occurrence of variance in spatial components. Motor equivalence can be defined as the ability of the sensorimotor speech control system to obtain the same end result with a vast amount of variation in the components of the movement (Netsell,1984; Sharkey & Folkins,1985). "Motor equivalence reflects complementary adjustments in a system's multiple degrees of freedom in accomplishing a particular goal." (Gracco & Abbs:1986:163). Research indicates the existence of a reciprocal relationship between the movements of different articulators. When a specific utterance is produced repeatedly, the extent to which each articulator (structure) deviates with each repetition varies. However, the total of the combined movements stays the same (Hughes & Abbs,1976; Kelso & Tuller,1983). Even under bite-block conditions, when the normal relationship between articulators is disturbed, speakers are able to compensate and produce an acoustically acceptable utterance (Folkins & Linville,1983; Kelso & Tuller,1983). This is also true in some cases of severe speech impairment, for instance "...gross compensatory adjustments by persons with open cleft palates or surgically removed tongues often cause speech pathologists to be amazed at how 'normal' the speech sounds are in the light of presumed anatomical incompetency." (Minifie, Hixon & Williams, 1973:253). This is evidence of a plastic and generative motor system (Van der Merwe,1986).

2.3.3.2.2. Sources of variance in temporal aspects of speech movements

The sound systems of all languages consist of a set of discrete phonemes that are invariant units lacking durational values. During the process of speech production phonemes are acted upon by an elaborate set of rules and are converted into phonetic units which do manifest durational values and temporal variability (Smith,1978). Each speech sound presumably has its own ideal duration which has to be specified during motor planning (Walsh,1984).

Durational properties observed at the phonetic output level are the result of both segmental qualities (e.g. vowel height) and suprasegmental factors such as stress, intonation, duration, juncture and rhythm (Smith,1978; Ohde & Sharf,1992). Suprasegmental features are language-specific and are variations larger than individual segments and are overlaid upon word, phrase, or sentence (Borden &

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Harris,1980). Each of these aspects has an effect on production. Stress for example is a complex signal marked by "...increased effort, intensity, pitch, duration and a change in formant pattern.... More articulatory effort is needed to produce a stressed vs. an unstressed syllable and vowels are longer in duration and tend to be of higher intensity in a stressed syllable, primarily due to greater sub-glottal air pressure." (Borden & Harris,1980:129).

Research indicated that _segmental_ _duration_ (duration of both vowels and consonants), has to be adjusted to the sound environment in which it occurs, and that this environment is language-specific (Smith,1978; Calvert,1980; Walsh, 1984). (This study will focus on the characteristics of first syllable vowel duration in the Afrikaans language). DiSimoni (1974:c) observed a form of motor equivalence named temporal compensation. "Temporal compensation in speech may be defined operationally as the effect which operates to modify the durations of internal segments of articulatory units in repeated productions so that the overall duration of the unit remains relatively constant." (DiSimoni,1974:c:697). Critical limits of equivalence may exist in segmental duration. In the Afrikaans language for example, lengthened vowel duration plays a phonological role as it distinguishes between some word meanings (Van der Merwe,1986).

Speaking _rate_ is one aspect of the suprasegmental feature speech tempo (or duration). Speech tempo can be described in terms of speaking rate, sound and syllable duration and pause duration and location (Ohde & Sharf,1992). Ohde and Sharf (1992:266-267) explained that "...differences in speaking rate reflect changes in the duration of the sounds produced and the pauses between them, both of which shorten as speaking rate increases and lengthen as speaking rate decreases.". Speaking rate is a temporal variable that can bring about radical changes in both temporal and spatial aspects of speech production (Kelso & Tuller et al.,1983). When speaking rate becomes either too fast or too slow, the production of speech sounds changes. At abnormally fast rates (above 8.0 syllables/second) the separate positions for different sounds cannot be achieved, and pauses are omitted (Ohde & Sharf,1992). At abnormally slow rates (below 2.0 syllables/second), speech sounds and pauses are prolonged to three or four

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

times their normal duration (Ohde & Sharf,1992). Changes in speaking rate may thus result in changes in segmental duration. Crompton (1980) found consonant duration more resistant to changes in speaking rate than vowel duration.

Voice onset time (VOT) is another temporal parameter that has to be controlled during speech production. Lisker and Abramson (1964) defined VOT as the time interval, in milliseconds, from oral release of a stop consonant to the onset of glottal pulsing in the following vowel. Kewley-Port and Preston (1974) explained that VOT-measurements reflect the time at which the adduction of the vocal folds is achieved relative to stop release. Tyler and Watterson (1991:131) described VOT as "....a temporal characteristic of stop consonants that reflects the complex timing of glottal articulation relative to supraglottal articulation.". VOT thus seems to reflect a complex aspect of supralaryngeal-laryngeal coordination and can be considered an example of *interarticulator-synchronization* (Tyler & Watterson,1991). According to Itoh and Sasanuma (1984) and Löfquist and Yoshioka (1981), VOT is a temporal aspect of speech that needs to be carefully controlled, and which is less variable than other temporal parameters.

Voice onset time also exhibits some intrinsic variations such as a function of place of articulation. As one proceeds from anterior to posterior oral occlusion, VOT increases as much as 20ms to 25ms for lag stops, while the opposite effect occurs for voicing lead (Lisker & Abramson,1964). VOT duration is also intrinsically affected by vocalic environment (Smith,1978). Observations indicate that VOT exhibits both inherent, language-universal characteristics and learned, language-specific properties (Smith,1978). A study of VOT in Afrikaans-speaking children will thus provide important language-specific durational information, as well as general information regarding interarticulator-synchronization in speech production control.

2.4. SPEECH MOTOR DEVELOPMENT: PRE-NATAL PERIOD TO TWO YEARS OF AGE

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Speech development can be considered a combined product of a developing neurobiological and an emerging behavioral system (Kent & Hodge,1991; Kent,1992). The course of speech and language development can be regarded as a "...correlate of cerebral maturation and specialization and of the child's physical development, although the exact nature of how growth and development interact with emerging speech is unknown." (Hodge,1993:130). Researchers need to be aware of how these biological factors may be reflected behaviorally (Hodge,1993), as they can contribute to observed speech behavior and consequently to the interpretation of research results. This discussion will concentrate on neurophysiological and motor control aspects of speech development, but it is acknowledge and emphasized that speech production is the *integrated result* of several different developmental processes and skills in areas of language, cognition, memory, hearing and perception.

Detailed developmental norms and specific stages of speech motor development are not yet known. However, existing research does indicate general trends in speech motor development, which may guide research and may present some theories with explanatory value of findings.

2.4.1. LEARNING AGAINST A BACKGROUND OF CHANGE

Probably the most important aspect of sensorimotor speech acquisition is the most obvious one, which is that "...all of the components are changing during development." (Smith et al.,1995:91). Sensorimotor speech development takes place against a constantly changing neurobiological environment (Netsell,1986; Hodge,1993; Smith et al.,1995). Continuous change occurs within all components of the speech motor system, namely the peripheral system, the neural system doing the controlling, as well as in the lower level control circuitry such as reflexes (Smith et. al.,1995). "The problem for the brain, which has to control the activity of the muscles to produce speech movements, is complicated by the fact that the systems to be controlled, the respiratory, laryngeal and oral systems, are changing dramatically." (Smith et al.,1995:91).

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Growth of *peripheral systems* that are controlled during speech production continues into adolescence and probably until the early twenties (Smith et al.,1995). Muscles and their loads (bones and soft tissues) get larger with age. As muscles get stronger, they may also change in the speed of their actions, becoming either faster or slower with age (Smith et al.,1995). Bones and soft tissue increase in size in non-linear ways. The mandible for example, does not show an orderly growth pattern where it becomes one percent larger each month of life. Rather, it shows growth spurts, where the relative proportions of the various parts of the mandible change with age. Normative data collected for measures of the head and face of children aged six to 18-years, showed that many different measures do not show parallel growth patterns and that different parts of the head and face grow at different rates (Farkas in Smith et al.,1995).

Not only does the peripheral system continuously change with age, the systems doing the *controlling* are also changing. Anatomical and physiological data show for example that the *cortex* is not mature at birth, and continue to mature well into adolescence. The *pathways* connecting the motor cortex to interneuron and motoneuron pools also continue to change into adolescence as myelination is completed, thus achieving higher nerve conduction velocities in adulthood (Smith et al.,1995). Table 2.3 provides a summary of some aspects of neural maturation from the pre-natal period to about 14 years of age, compiled from Netsell (1986).

According to Smith et al. (1995) recent research showed that even the *lower level circuitry* of the brain, such as reflexes, continues to develop into adulthood. Barlow (in Smith et al.,1995) found that perioral reflexes, responses of lip muscles to mechanical stimulation of the lips, are present in infants, but that responses are not organized in the same way as in adults. Compared to those of adults, responses in infants are of longer latency, lower amplitude and are diffuse or non-specific. Smith et al. (1995) also reported from work in their laboratories where they have mapped the characteristics of reflex circuitry through which stimulation of intra-oral sites affects the jaw muscles. They found that these reflex responses were very small or non-existent at age four, but that by seven years of age they were extremely large and long lasting.

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

TABLE 2.3: STAGES OF NEURAL MATURATION SUMMARIZED FROM NETSELL (1986)

PRE-NATAL PERIOD	THE NEONATE: BIRTH TO THREE MONTHS	THE BABBLER: THREE TO TWELVE MONTHS	THE TODDLER: 12-24 MONTHS	REFINEMENT PERIOD: TWO TO 14 YEARS
In the period of four to nine fetal months, several basic neurological structures undergo considerable or nearly complete myelination including the: *lower motor neurons *pre-thalamic auditory pathways (The postthalamic auditory pathways, however, do not fully myelinate until around the fourth or fifth year). *pre- and post-thalamic exteroreceptive and proprioreceptive routes *portions of the inferior cerebellar peduncle.	*Myelination charts indicate that major neural connections being formed and nearly completed in this stage is the pre- and post-thalamic optic tracts. *An important event of myelination with respect to sensorimotor control that begins at or near birth involves the upper motor neuron (corticospinal and corticobulbar) tracts and post-thalamic auditory and somatosensory pathways. *First evidences of myelination are also reported for the middle cerebellar peduncle, corpus striatum and frontopontine pathway. *The inner cell layers of the cerebral cortex (especially the primary motor and sensory areas) are fairly well developed in this period, suggesting that some of the observed movement patterns of the newborn are utilizing the cortical levels. *For the most part, primitive reflexes are obligatory at this point, and the general assumption is that that they remain so until the cortical mechanisms begins to inhibit them at about three months. *Sub-cortical neural mechanisms dominate in this period.	*Major developments occur in pyramidal tract (corticospinal and corticobulbar) myelination as well as postthalamic somatosensory pathways. *The major development in 'hardwiring' of the middle cerebellar peduncle is formed in this period, and the input-output at this level of the cerebellum is generally regarded as the key neural component for cerebellar function in speech motor control. *The beginning and completion of corpus striatum myelination occur in this nine month period, which seems a reasonable neuro-anatomic correlate for the postural and movement developments that occur. *Also of major importance to the development of motor control is the considerable myelination seen in the postthalamic auditory projections. *Assuming the child is forming 'critical auditory-motor linkages' at this time, the already described developments of the motor, somatosensory and auditory systems are quite timely.	*Full myelination of the postthalamic somesthetic pathways is not complete for most normal children until about 18 months - also a point at which most children walk unaided. *From a speech motor perspective, this final 'hard wiring' of the somatosensory pathway puts the child in touch with his cerebral cortex, and motor cortex in particular, such that the emerging speech movement patterns can be practiced using the full range of the fast acting cortical-cerebellar-somatosensory-thalamic-cortical loops. *Considerable growth occurs in the cerebral neocortex during the 12 to 24 month period. Most of the layers of the cortex are vertically connected (with respect to the neuraxis) and horizontal connections between association areas are just getting underway. *Myelination of the cerebral commisures, which was initiated in the previous period shows a marked growth in the second year, but does not near completion until the seventh year.	*The middle cerebral peduncle is fully myelinated around three to four years of age and the possthalamic acoustic pathways at four to five years of age. *The cerebral commissures complete their myelination at about seven years, whereas the secondary association areas continue myelination until the third decade of life, if not longer.

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In adults these responses have shorter latencies but are smaller in amplitude compared to those of seven-year-olds. Smith et al. (1995:92) commented that "This evidence is contrary to the old notion that reflex circuits were present at birth and disappeared with development. Rather, these studies suggest that some oral reflexes are actually being established at the same time that speech motor learning occurs.". However, more investigation is needed in this area in order to expand existing data and to determine when and how the neural circuitry attains adult-like properties in normal developing children.

2.4.2. STAGES OF MOTOR AND VOCAL DEVELOPMENT FROM BIRTH TO TWO YEARS OF AGE, WITH REFERENCE TO SOME NEUROBIOLOGICAL AND PHYSIOLOGICAL DEVELOPMENTAL ASPECTS

Since so many questions remain unanswered in the field of sensorimotor speech development, and because of the limited amount of normative data, it is very difficult to identify clear periods, stages, or phases of development. However, with reference to certain neurobiological, physiological and vocal developmental data, it is possible to construct hypothetical expected periods of speech development up to about two years of age. In infancy, the development of any form of vocalization needs to be considered, because such behaviors are the precursors of speech (Smith et al.,1995). The discussion of speech motor development for the first two years of life will be divided into the pre-natal period, the period of birth to three months, the babbler-period (three to 12 months) and the toddler-period (12 to 24 months).

2.4.2.1. The pre-natal period

In the period of four to nine fetal months, the fetus develops a number of movement routines, some which will be called into action as he moves at birth from the medium of water to air. Neural functioning systems to support survival at birth namely breathing, sucking and swallowing are developed and fully

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practiced at this period (Netsell,1986). Orofacial responses such as gagging, sucking, swallowing, and jaw extension among others, occur. At birth the facial nerve connections to the lips are complete, while those to the other muscles of facial expression are not. Although breathing is sometimes initiated by the fetus (implying sufficient neural innervation of the diaphragm), full neural innervation of the respiratory system is not complete until eight months after birth (Netsell,1986).

2.4.2.2. The neonate (birth to three months)

During the infant's first three months, the most notable motor act for the listener is crying (which has its own developmental course), and fussing (Netsell,1986). Vegetative sounds such as burping and coughing also occur, together with grunts and sighs (Smith et al.,1995). According to Smith et al. (1995) phonation and respiration are probably coordinated by automatic brain stem mechanisms in cry during this phase. Netsell (1986) argued that it is debatable, but unlikely, that the respiratory-laryngeal mechanics, muscle forces, and aerodynamics developed in crying are pre-requisites or co-requisites for the development of respiratory-laryngeal controls used for speaking. Research showed that forceful cries associated with pain or distress are generated with subglottal air pressures in excess of 60cmH_2O, where values of five to 10cmH_2O are used for child and adult speech (Bosma, Truby & Lind,1965; Hixon in Netsell,1986). Infant vocalizations in "non-distressed" modes probably are considerably closer to the respiratory-laryngeal controls used for speech development (Netsell,1986). (See 2.4.3. for further discussion of vegetative and non-speech oral movements and their relationship to speech motor development).

Vocalizations towards the end of the first 90 days of life are largely vocalic, nasalized and of short duration (Oller in Netsell,1986). Netsell (1986) argued that this may not be surprising, as preliminary observations suggested that the respiratory contributions to these vocalizations are made entirely in the expiratory phase of tidal breathing, and without opposition of the rib cage and abdominal movements (Hixon in Netsell,1986). All sound productions of the infant indicate a rather simple functioning of the larynx. In terms of upper airway movements there are firstly no indication that the velopharynx is alternately opening and closing for speech and secondly, the tongue and jaw move as a single piece to effect velar-like stops (with the infant reclining or on his/her back) or apicals (e.g. "da-da-da" or "na-na-na"). Thirdly, lip-jaw independence is seldom seen for front-of-the-mouth speech movements in this period (Netsell,1986). The lack of tongue and lip independence from jaw movements during speech-like vocalizations of this period, is in contrast to lip-jaw independence observed in smiling (Wolff,1969), or tongue-lip responses independent of jaw movement in response to tactile stimuli (Weiffenbach & Thach in Netsell,1986). In summary it can be said that "...the neonate appears as a rather sophisticated sound generator (by adult standards), who may occasionally surprise himself and other listeners with 'speech' by simply opening and closing his mouth while phonating." (Netsell,1986:14).

2.4.2.3. The babbler (three to twelve months)

The period three to twelve months "...may be the single most sensitive postnatal period with respect to the eventual acquisition of normal speech motor control. Delays or other abnormalities that appear or remain in this period, would seem to have extremely serious consequences in terms of building the fundamental speech movement routines that are later refined in the overall coordination of the speech mechanism." (Netsell,1986:14). It is also a period of rather dramatic changes in the musculoskeletal system (Netsell,1986). The early period of the babbler also marks the infant's initial struggle with gravity in terms of the probable effects on speech production (Netsell,1986). In beginning to speak while sitting up or semi-reclining, the three-month-old infant almost spontaneously assumes adult-like usage of rib cage and abdominal movements (Hixon in Netsell,1986). The levels of lung volume and inspiratory-expiratory ratios used in speaking at seven months are essentially adult-like. During three to twelve months downward-forward growth of the mandible is more rapid than other cranio-facial expansions. The larynx moves markedly downward (around four to six months) as the mandible-hyoid-laryngeal suspension system develops, and the upper airway assumes more adult-like dimensions (Kent in Netsell,1986).

Smith et al.(1995) identified four stages of vocal development that the infant progresses through in the short time span of two to fourteen months of age. These are the *control of phonation* stage (two to four months), the *expansion or vocal play* stage (five to six months), the *canonical babble* stage (seven to nine months) and the *variegated babble* and *first words* stage (10 to 14 months). These stages support the notion that the first 12 to 14 months of life is an important period characterized by a rapid development of speech motor skills. Netsell (1986:16) hypothesized that the existence of a *transition stage* between the periods of the neonate and babbler, may "..mark the onset of emergence for movement sub-routines that will eventually form the efferent-afferent feedback (auditory-movement-somatosensory feedback) substrata of adult speech motor control.". Netsell (1986) called this period that of the "*y*abbler" (Netsell, 1986:16), in recognition of the "*yeah*" sound the infant can produce by simply raising and lowering the jaw fast enough to blend the [æ] and [i]-vowels together.

During the *control of phonation stage* (at approximately two to four months), comfort or cooing sounds are produced, which may reflect a transition to less automatic behavior that is beginning to be organized at higher levels of the nervous system (Smith et al.,1995). Although vowel and consonant-like sounds may appear, true consonants and vowels are not yet present. Consonant-like sounds generally are produced at the back of the mouth, where the tongue and palate make contact. Syllabic nasals or nasalized vowel-like sounds also emerge. Late in this phase, infants progress from producing single sounds, to series or strings of vocalization, while sustained laughter also appears (Smith et al.,1995).

An *expansion stage,* which can also be called the *vocal play stage* according to Smith et al. (1995), occurs between the ages of five and six months. During this time period longer series of syllables and prolonged vowels and consonants are produced. Substantial variation in production occurs among infants, but

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examples of typical occurring sounds include: "...high pitched squeals, grunts, growls, pharyngeal frication, trills, raspberries, inspiratory sounds, syllabic nasals, clicks and trills." (Smith et al.,1995:93). As babies begin to play with loudness and pitch parameters, yelling and pitch variations are observed. Infants aged five to six months produce a variety of supraglottal (articulatory) constrictions and also display increased coordination of articulation and phonation (Smith et al.,1995). The voiced-voiceless contrast is established routinely by six months and according to Netsell (1986), this suggests that the adductor-abductor muscles of the larynx have at least the beginning of reciprocal action. "Finer gradations of voice fundamental frequency for pitch variations in phrases of declaration and question indicate more precise control of muscle contraction in a non-reciprocal situation." (Netsell,1986:17).

A stage of *canonical babble* occurs between the ages of seven and nine months (Smith et al.,1995). Canonical, or reduplicated babbling can be defined as the production of rhythmic, repetitive consonant-vowel sequences that contain the same consonant and vowel within each syllable e.g. [bababa] and [adadada] (Smith et al.,1995).Consonant and vowel transitions are rhythmical, while timing is well-controlled. When two to four syllables appear in a single expiration, the more typical shapes are consonant-vowel (CV), vowel-consonant (VC) and vowel-consonant-vowel (VCV) (Netsell,1986). In terms of motor complexity, this only requires that the child starts with the oral tract constricted and open it (CV), or open-close-open it. Netsell (1986:17) hypothesized that through the "yabbling-period", the infant begins generating these basic syllable types by simply lowering and elevating the jaw while phonating.

Smith et al. (1995) noted that canonical babbling tends to be self-stimulatory rather than interactive. Further, the disappearance of canonical babbling emerges within the same time period as repetitive, rhythmical movements in other "motor effectors" (Smith et al.,1995:94). For example, rhythmical movements of the hands and arms are often seen in infants in this stage. It appears then as if "...canonical babbling may be a reflection of a general propensity for rhythmical movement..." however, "...it has also been suggested that canonical babbling

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marks the first phase of vocal behavior which is truly related to emergent language processes." (Smith et al.,1995:94).

Somewhere between three and nine months jaw independence from lower lip and tongue movements emerges for most children, as inferred from reports of consonant productions such as "r,s,z,th" and "w". A full range of vowels and diphthongs is also developed in this period, implicating shifts and shaping of the entire tongue body (Netsell,1986). Finally, nasal and non-nasal contrasts [m/b] and [n/d] appear in the three to 12-month period, signaling the probability that at least gross contractions of the palatal levator takes place (Netsell,1986). Netsell (1986:17) argued that from adult physiology, it seems reasonable to predict that the nasal contrast will precede the voicing contrast developmentally, because "...complete or near-complete velopharyngeal closure accompanies the voiceless consonant productions.".

2.4.2.4. <u>The toddler (12 to 24 months)</u>

Examination of motor milestones shows that most one-year-olds are beginning to walk at about the time they start to produce their first words (Shirley in Netsell,1986). However, "The practice of walking *or* talking seem to 'tie up' all the available sensorimotor circuitry because the toddler seldom, if ever, undertakes both activities at once." (Netsell,1986:18). The 12 to 24 month period is marked by "..considerable practice and refinement of speech motor skills acquired in the previous period, as well as the acquisition of more and more complex speech movement patterns." (Netsell,1986:18).

Smith et al.(1995) identified a stage called *variegated babble and first words* in the age range 10-14 months. This period is characterized by increasingly varied and complex babbled productions that contain a variety of sounds and intonation patterns within the same strings. It's beyond the scope of this study to engage in a detailed discussion of the issue, but it should be noted that theorists continue to debate whether babbling sounds are the direct precursors of speech (the *continuity hypothesis*), or whether babbling sounds bear no direct relationship to later speech skills (the *discontinuity* hypothesis) (Lane & Molyneaux,1992). Jakobson's (1968) viewpoint was that babbling is only a randomly produced series of vocalizations during which a "...multitude of sounds were produced with no apparent order or consistency." (Lowe,1994:36). Further, such behavior was thought to be clearly separate from the "...following systematic sound productions evidenced in the first words..." (Lowe,1994:36). Lowe (1994:36) argued that research since 1968 has "...repeatedly documented that (a) babbling behavior is not random; rather, the child's productions develop in a systematic manner, (b) not all sounds are randomly produced during this babbling stage but a subset of phones occur more often, and (c) the transition between babbling and first words is not abrupt but continuous; late babbling behavior and the first words are very similar in respect to the sounds used and the way they are combined.". Recent evidence showed that babbling and first words acquisition form a continuous process, since segmental and prosodic features are incorporated into early word productions (Smith et al.,1995). A child who prefers the form [ba] in her pre-linguistic babble, for example, is likely to acquire words of particular similar phonetic structure, such as 'ball" and 'bottle" in her early lexicon. Motor preferences and early linguistic production thus appear to be related (Smith et al.1995). In contrast, however, other research has shown that vowels used in early babbling do not show such a strong relationship to early meaningful speech as consonants do (Davis & MacNeilage,1990).

The emergence of words in the time range 12 to 24 months, coincides with the "...completion of 'hard-wiring' in the major sensorimotor pathways believed to operate in speech motor control and a period of stabilization in musculoskeletal growth." (Netsell,1986:18). "If locomotion practice in the early part of this period is that of the toddler, the speech motor skill might be characterized as that of the *wobbler*." (Netsell,1986:19). By the end of the 12 to 24 month-period most normal children would have frequently practiced almost all of the single consonant and vowel combinations of their mother tongue, some consonant blends as well as most diphthongs (Netsell,1986). The speech movements involved in productions are, however, slower than that of adults and segmental duration may be more variable than that of adults (Netsell,1986). According to

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Netsell (1986) this period also seems a reasonable time for the child to be learning some of the gross coordination between the functional components of the speech production system.

2.4.3. THE RELATIONSHIP OF SPEECH TO OTHER ORAL MOTOR BEHAVIORS

A full description of normal sensorimotor speech development "...depends on an understanding of the relationship between developing speech motor coordination and the coordination of other emerging oromotor behaviors." (Ruark & Moore,1997:1373). This relationship needs to be established since it will determine whether non-speech oral motor behaviors are included in an assessment battery of speech motor development, will effect clinical treatment decisions with DSD, and will contribute to our understanding of normal developmental and mature speech processes (Smith,1978; Ruark & Moore,1997). For example, speech language pathologists that view speech and non-speech behaviors to be closely related, may evaluate and train pre-speech behaviors such as chewing, sucking, swallowing or non-speech oral movement sequences (e.g. blowing or tongue lateralization movements) as fundamentals to speech motor development. Two dominant hypotheses can be identified regarding this issue. One where speech is viewed as an *emergent* behavior from earlier appearing oromotor behaviors (*dynamic pattern perspective*), and a second in which speech is viewed as a unique, *new* motor skill, which develops independently from other skills (Moore & Ruark,1996; Ruark & Moore,1997). Presently, support exists for both views.

The first line of reasoning is built on "...mechanisms of pattern generation which have been directly observed in animals as well as dynamical systems theory... A *dynamical pattern perspective* might suggest that speech movements emerge gradually through an interaction of context (i.e. external conditions), with intrinsically generated patterns stemming from the rhythmic movements of sucking, chewing, reduplicated babbling and variegated babbling." (Moore & Ruark,1996:1034; *emphasis provided*). A first aspect in favor of this hypothesis is the child's capacity to take advantage of redundancies across behaviors and to adapt his/her repertoire of skills to new and changing behavioral demands (Fentress in Moore & Ruark,1996). The reliance of speech and non-speech behaviors on the same "...neurophysiological infrastructure (i.e. shared musculoskeletal systems and neural connectivity)..." leads to the position of an "...organizational hierarchy based on a common coordinative organization." (Moore & Ruark,1996:1035). This implies that existing behaviors are modified to achieve new movement goals (e.g. Kent, Michiel & Sancier in Ruark & Moore,1997) and that motor development only entails modification of existing patterns (Ruark & Moore,1997). "Muscle synergies from centrally patterned activities merge to create new muscle synergies for speech that may then be independently controlled by higher order mechanisms." (Ruark & Moore,1997:1374). A third source of support for this hypothesis can be drawn from models of speech production that incorporate the function of central pattern generators in speech production. "The essential assumption of these models is that there exist small, neural populations, possibly central pattern generators .....capable of establishing or influencing the motor organization required by such complex, rhythmic behavior such as mastication, respiration, phonation, swallowing, and sucking. It is further assumed that the coordinative organization afforded by these neural circuits can be brought to bear during speech production." (Moore & Ruark, 1996:1035). Grillner (in Ruark & Moore,1997) for example, suggested that speech production consists of a combination of centrally generated motor patterns such as those underlying respiration, swallowing and mastication.

An alternative view of the relationship between speech and non-speech oral behavior is that speech develops independently of existing behaviors, emerging as a *new and unique motor skill*. Support for this hypothesis is found in the observations of babbling rhythmicity and further relies on findings that the coordinative organization of mature speech is distinct from that of any of the postulated precursors (Moore & Ruark,1996). Investigations of mandible muscle activity of adults during chewing and speech tasks indicated that chewing patterns are characterized by reciprocal activation of mandibular antagonists,

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while *coactivation* of antagonists is the dominant pattern of activity for speech (Moore,1993). "The established orofacial coordination available to children from these behaviors does not appear to be well-suited for speech. For example, kinematic and positional control characterizes speech coordination, whereas force generation is probably one of the primary goals of coordination for chewing. According to this view the coordinative frameworks of nonspeech contribute little toward meeting the priorities of speech." (Moore & Ruark,1996:1034-1035). Ruark and Moore (1997) similarly found that two-year-old children demonstrated task-specific differences in coordinating organization for lip muscle activity for speech and nonspeech behaviors (chewing). This further supports the suggestion that speech develops separately and distinctly from developing oromotor behaviors such as chewing, and that children develop speech-specific coordinative mechanisms very early in life (Ruark & Moore,1997).

Netsell (1986) argued along a different line in favor of the view of speech as a unique, emerging developing skill. He suggested that in the light of embryological and postnatal neural development, the existence of a "...microneuro-anatomy..." (Netsell,1986:24) for speech movements seems entirely plausible. According to Netsell (1986:24) evidence suggests that "...speech and vegetative neural commands are conceived as parallel inputs that would compete at some level of the neuraxis for the 'final' effector neurons if issued simultaneously. It follows that the vegetative command neurons might be inhibited or otherwise quieted during speech activity.". Such an argument holds that the practice of vegetative and/or non-speech oral movements would serve only to facilitate the vegetative synapses that must be inhibited during speech production and as such would be "counterintuitive" (Netsell,1986:25). However, more evidence is needed to confirm these speculations.

Presently, overwhelming results in favor of one of the two hypotheses regarding the relationship between speech and non-speech oral behaviors have not been obtained. Evidence for both hypotheses exists and more longitudinal data are needed before any conclusions can be drawn. Since the exact relationship

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between speech and non-speech behaviors has not yet been established, non-speech oral movements (i.e. single, two-sequence and three-sequence non-speech oral movements) will be included in the test battery of this study for the sake of completeness.

2.5. SPEECH MOTOR DEVELOPMENT AFTER TWO YEARS OF AGE

Netsell (1986:19) stated that if the first 24 months of vocalization and verbalization can be thought of as a "speech emergence period", the ages from two to fourteen years may be called "a speech refinement period" in terms of speech motor control development. Although adult listeners may consider the speech of a seven-year-old for example, to be adult-like, research had shown overwhelmingly that temporal and spatial aspects of speech movements are still far from adult-like at this time (e.g. Kent,1976; Netsell,1986; Smith & Kenney,1998). However, due to a limited amount of research in the area of sensorimotor control and the diverse nature of existing research about sensorimotor speech control development in children after two years of age, we do not yet have norms indicating possible phases of development. Collectively though, the diverse research attempts do indicate some basic differences between the sensorimotor speech skills of adults and children though. A review and evaluation of existing information form the basis of research planning and the eventual interpretation of results. Existing research regarding speech motor development can be divided in terms of studies that focused on aspects such as voice onset time, segmental duration, variability of speech movements and coarticulation and/or coordination.

An aspect that limits deductions and generalizations in the area speech motor development, is the fact that research is characterized by the usage of a variety of sometimes very sophisticated instruments. The reader is referred to Table 2.4. for clarification, since it provides a description of the most commonly used instrumentation analysis procedures in research and their main advantages and

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disadvantages. When the information in Table 2.4. is reviewed, it is obvious that acoustic analysis (which will be incorporated in this study), is one of the least invasive, relatively easy and more readily available analysis procedures that can be used in the research of speech motor development. No further descriptions of measurement instruments will be provided in the following discussion.

2.5.1. DEVELOPMENT OF VOICE ONSET TIME (VOT)

2.5.1.1. General developmental trends in VOT

As previously described, (VOT) reflects a complex aspect of laryngeal and supra-laryngeal coordination and is therefore an example of interarticulator-synchronization (Tyler & Watterson,1991; Van der Merwe,1997). VOT seems to be the one aspect of speech motor development that was most studied through the years, employing acoustical (i.e. oscillographic and spectrographic) analysis. However, most of these studies were conducted in American English and subjects were usually very young.

Although adult studies showed that the range of VOT-values in different languages is very similar, the extent of variation across languages suggests that language-specific adaptations may also occur (Smith,1978). For example, the Spanish short-lag category seems to differ somewhat from the English short lag category (Lisker & Abramson,1964), and Swedish long-lag stops may exhibit somewhat greater durational values than English long-lag stops (Fant in Smith,1978).

In other languages such as Dutch (and Afrikaans) where aspiration of stops is not such a common phenomenon as in English (Lisker & Abramson,1964), stops may also have different VOT-values (e.g. voiceless stops in these languages can be expected to generally not have VOT-values in the long-voicing lag range). No comprehensive study of VOT-values in normal developing Afrikaans-speaking children could be identified.

TABLE 2.4: INSTRUMENTAL ANALYSIS PROCEDURES

INSTRUMENTS	WHAT IT MEASURES	ADVANTAGES	DISADVANTAGES
Acoustic Analysis * Spectrograph * Oscillograph * Cspeech computer program: LPC (Linear Predictive Coding of the waveform) & Fourier spectra	- The acoustic signal provides temporal and spectral information about factors such as: * speaking rate * acoustic configuration for vowels and consonants * rates of change in the overall configuration of the vocal tract * flexibility of articulatory behavior * aspects of phonatory behavior (Forrest & Weismer,1997)	* Forrest & Weismer (1997:63): "..the acoustic output of the vocal tract contains the product of the *entire* speech system's effort, rather than an isolated component of that effort." * Completely *noninvasive* thus suitable for use with children. * Forrest & Weismer (1997:63): "...computer-based analysis of speech acoustics have become highly *sophisticated*, *accessible*, and relatively *cheap*....is therefore within the reach of many clinicians for diagnostic, data keeping and research purposes.".	* A certain amount of training, sophistication, and expertise is required for analysis and interpretation. * Comparisons of spectra across subjects need to be made with care due to differences in physical dimensions (e.g. vocal tract size, oral cavity size). * Many factors can influence segment durations and vowel formant frequencies e.g. speaking rate, phonetic context and position in utterance.
Aerodynamic Measurement * *Air pressure* -Catheter in mouth attached to pressure transducer and recorder * *Airflow* -Pneumotactograph	* Aerodynamics of speech production: - Intra-oral and nasal pressures - Airflow: nasal emissions & nasal airflow - Structural performance * Provides information about the respiratory aspects of speech production such as maintenance of glottal pressure and sufficient bilabial or lingual-palatal obstruction (tongue placement) as well as velopharyngeal aspects such as adequate velopharyngeal closure. * Structural performance: - Measures constrictions of upper airway structures such as tongue, teeth, lips and palate that influence airflow and pressure (resistance measurements) (Warren, Putnam-Rochet & Hinton, 1997).	* Provides a wide range of information about structural performance of the speech mechanism. * Provides information about the integration and coordination of sensorimotor processes (Warren, et al.,1997). * New developments suggest that aerodynamic measurements may be utilized in combination with apparatus that provide resistance loads, to assess sensory components of speech in future (Warren et al., 1997).	* A certain amount of training, sophistication and expertise is required for analysis and interpretation * Expensive and sophisticated instruments are needed * Children may resist apparatus (such as catheter in mouth) resulting in poor co-operation. Correct body posture for example is also necessary to obtain reliable results and children may find it difficult to sit quietly for a long period.

TABLE 2.4 (-CONTINUED): INSTRUMENTAL ANALYSIS PROCEDURES

INSTRUMENTS	WHAT IT MEASURES	ADVANTAGES	DISADVANTAGES
Kinematic Measurement * *Orofacial movements:* -head-mounted lip-jaw movement transduction system -orofacial tracking with x-ray microbeam -orofacial magnetometry * *Tongue movements:* -glossometry -optical tracking -palatometry * *Velar and laryngeal movements*: -velopharynx: cineradiography, video-nasendoscopy, electro-mechanical and opto-mechanical transduction of velar displacement, flexible-fiber optic nasendoscopy -fiber-optic naso-pharyngoscopy and laryngoscopy, electroglottography * *Chest wall movement:* -chest wall magnetometry -strain gage belt pneumograph	* Vocal tract kinematics of the lips, tongue, mandible, velopharynx, laryngeal system and chest wall. * Kinematic variables include: -amplitude of displacement -velocity -acceleration -phase and relative timing among multiple articulatory structures -phase relations to EMG muscle patterns -spectral properties of movement (Smith in Barlow, Finan, Andreatta, Ashley Paseman,1997)	* Accurate and extensive articulator-specific movement information can be obtained. * Recordings from multiple structures (e.g. lips, tongue, velopharynx, mandibular system, laryngeal system and chest wall) allow understanding of the trading relations between structures, patterns of organization, and re-organization following brain injury or disease (Barlow et al.,1997). * Some kinematic methods are cost-effective e.g. headmounted lip-jaw movement transduction. * Strain-gauge systems have low-initial cost, easy maintenance and operation and non-invasive application.	* A certain amount of training, sophistication, and expertise is required for analysis and interpretation. * Most of these instruments are expensive e.g. an EMMA-system (i.e. electromagnetic midsaggital articulometer) which is an excellent system providing information (i.e. large quantities of kinematic data and of low risk to subjects) of about ten channels of high-resolution kinematic recordings of intra-oral structures such as the tongue and velum, but costs about $90 000 (Barlow et al.,1997) * Kinematic instruments usually require that the child tolerates some apparatus on the head, in the mouth or on the face/chest e.g. radiosense markers/pellets, a headband, a pseudo-palate, bead electrodes, transducer under the chin, magnetic coils. * Not easy to use with children as factors such as movement and fatigue may influence co-operation and reliability of data.
Electromyographic Measurement * Electromyogram (EMG)	* Measurement of very small electrical currents (potentials) generated by contracting muscles – the EMG-signal. "...the size of the EMG signal bears a monotonic relationship to the degree to which the muscle has been activated." (Luschei & Finnegan,1997:152). * Amplitude of waveform * Temporal properties of waveform	* Gives an indication of motor unit function * Diagnostic value: "The diagnosis of motor disorders in neurological clinics is currently the main well-established clinical use of EMG-recordings and analysis." (Luschei & Finnegan,1997:150).	* Subjects have to tolerate apparatus such as metal disk electrodes, rigid needle electrodes and bipolar hooked-wire electrodes that are unsuitable for use with children. * Sometimes difficult to determine whether amplitude is normal or abnormal, while the beginnings or ends of EMG-activity usually are somewhat arbitrary (Luschei & Finnegan,1997).

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Cross-linguistic information about VOT-development may present interesting information regarding language-specific adaptations of VOT, which may provide more insight in the general sensorimotor control of VOT. Existing research of VOT in American English-speaking children provides a foundation for broad comparison and may indicate general developmental trends in VOT. The reader is referred to Table 2.5. for a summary of terminology to be used in the following discussion (e.g. short voicing-lag and voicing lead).

Research findings indicate a fairly systematic developmental sequence of acquisition of the voicing contrast and corresponding changes in VOT, although striking individual age differences with respect to the age of acquisition are also evident (Kewley-Port & Preston,1974; Menyuk & Klatt,1975; Kent,1976; Gilbert,1977; Smith,1978; Macken & Barton,1980; Enstrom,1982; Tyler & Watterson,1991; Kuijpers,1993; Snow,1997). This conclusion is based on a combination of results of mostly acoustic studies that focused on the nature and VOT-distributions of voiced and voiceless stop productions. Although these studies differ slightly in terms of methodical aspects such as division of age groups and material used, their findings are comparable and more or less homogeneous.

2.5.1.1.1. Early acquisition of VOT

Stops do not occur in neonatal vocalizations, but first appear around six months of age, during babbling, with a wide range of values randomly distributed from voicing lead to long voicing-lag (Kewley-Port & Preston,1974).

Some months later, a concentration of apicals (alveolar stops) in the *short voicing-lag* category occurs (unimodal distribution), with alveolar stops in the long voicing-lag category then gradually added (Kewley-Port & Preston,1974; Macken & Barton,1980). It is reported that infants of one year of age, produce primarily voiced stops (thus favoring pre-voiced or short voicing-lag for stops) of their native language, regardless of linguistic community (Enstrom, 1982; Tyler & Watterson,1991).

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
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TABLE 2.5: TERMINOLOGY USED IN VOICE ONSET TIME STUDIES

TERM	DEFINITIONS AND DESCRIPTIONS OF VOT FROM THE LITERATURE
Voice Onset Time (VOT)	* Tyler and Watterson (1991:131-132): "VOT is a temporal characteristic of stop consonants that reflects the complex timing of glottal articulation relative to supraglottal articulation....VOT is a reliable, relatively easy measurement to make and is thought to reflect a complex aspect of supralaryngeal-laryngeal coordination.". *Voice onset time can be defined as the "....interval between the release of the stop and the onset of glottal vibration, that is, voicing." (Lisker & Abramson,1964:252). *Kewley-Port and Preston (1974:197): "VOT is measured as the interval between the first vertical striation, representing glottal pulsation, and the onset of energy ('burst'), representing the release of stop occlusion.". *Kewley-Port and Preston (1974:203): " ....VOT measurements reflect the time at which the adduction of the vocal folds is achieved relative to stop release.".
Negative (-) VOT value / voicing *lead* / *pre*-voicing	*Tyler and Watterson (1991:132): "VOT values for voiced stops can also fall into what is called the voicing lead (-) or pre-voiced range, if glottal pulsing precedes articulatory release.". *Kewley-Port and Preston (1974:197):"When the glottal pulses precede the stop release (voicing lead) the VOT-value is given a negative sign.". *Tyler and Watterson (1991:131): "...negative VOT-values indicate that glottal pulsing begins before the release burst (pre-voicing).". * The ***voicing-lead range*** reported for adults range from **-125 milliseconds (ms) to -1ms** (Tyler & Watterson,1991) * Kewley-Port and Preston (1974:204): "...to produce voicing lead stops, the infant must complete glottal closure considerably before oral release and then initiate and sustain vocal fold oscilliation by the addition of other articulatory mechanisms.".

TABLE 2.5. (-CONTINUED) : TERMINOLOGY USED IN VOICE ONSET TIME STUDIES

TERM	DEFINITIONS AND DESCRIPTIONS FROM THE LITERATURE
Positive (+) VOT value -also called _voicing lag_ *(Note: Referred to in the literature as either short or long -see further)*	*Kewley-Port and Preston (1974:197): "..when the stop release precedes the glottal pulses (voicing lag), the VOT value is positive.". *Tyler and Watterson (1991:131): "Positive VOT-values indicate that glottal pulsing begins after the release burst.".
Short voicing-*lag* -also called *short-lag (+) voicing range*	* VOT-values for English voiced stops [b/d] and [g] for example, fall in the *short-lag* voicing range because there is a short lag between the supraglottal articulatory articulatory release and the first glottal pulse (Tyler & Watterson,1991). * Short lag voicing ranges reported for English-speaking adults by Lisker & Abramson (1964) vary according to *place* of articulation e.g.: _labials_: 0ms to +5ms _alveolars_: 0ms to +25ms _velars:_ 0ms to +35ms *Kewley-Port and Preston (1974:203-204) described the articulatory gestures involved in apical (i.e. alveolar) stop production, which falls in the short voicing lag range in English, as follows: "Thus, articulatory gestures required to produce _short voicing lag stops_ are velopharyngeal closure followed by the complete adduction of the vocal folds at the time of release of the supraglottal articulators, such that vocal fold oscillation begins within 20ms of release.....thus, for an infant to successfully produce short lag apical stops in initial position, he may fully close the glottis any time during apical closure providing that the velopharyngeal closure merely isolates the nasal cavities". *For the purposes of _this study_ any VOT-value between **0 and +39ms** will be considered to fall in the ***short-lag voicing range*** or category.
Long voicing-*lag* -also called *long-lag (+) voicing range*	* Kewley-Port and Preston (1974:204): "Stops with long voicing lag are produced with the glottis open at the time of release…an infant will successfully produce a long voicing lag stop if he leaves the glottis open throughout apical closure and then initiates vocal-fold adduction approximately at stop release, having maintained velopharyngeal closure throughout.". Kewley-Port and Preston (1974:197) considered long voicing lag to begin "…where stops have VOT-values greater than +40ms". * Lisker and Abramson (1964) consider the long voicing lag range to include VOT-values from +40ms to +100ms. *For the purposes of _this study_ any VOT-value of **+40ms and above** will be considered to fall in the ***long-lag voicing range*** or category.

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

This may indicate that similar articulatory adjustments underlie alveolar stop productions of 12-month-olds of different languages (Enstrom,1982). The majority of stops in early words are thus characterized by the occurrence of a short delay between articulatory release and the onset of vocal fold vibration (Kent,1976). In order to produce the voicing contrast, the young child has to learn to coordinate the timing of velopharyngeal closure, closure of the supraglottal articulators, vocal fold oscillation, and release of supra-glottal articulators (Tyler & Watterson,1991).

Some authors have theorized that voicing for English *long voicing-lag stops* may be more carefully controlled than for English *voicing lead* or *short voicing-lag* stops (e.g. Kewley-Port & Preston,1974; Gilbert,1977). Kewley-Port and Preston (1974:203) hypothesized that "...the contrastive differences in the voicing dimension of stops are primarily the result of differences in the timing of glottal articulation relative to supraglottal articulation. We propose that distinct physiological mechanisms underlie the production of stops within each of the three voicing categories and, further, that stops in the *short voicing lag* category are easier to produce than stops in the two other categories.".

A perceptible contrast occurs when children subsequently modify their productions toward adult VOT-ranges for voiced and voiceless stop consonants. Evidence that children have acquired the appropriate phonological contrast may be found in productions of children as young as 1;5 years (Macken & Barton,1980) and 1;9 years (Snow,1997). However, it may take up to another 11 months before adults may perceive the contrast. Considerable progress is usually made towards the production of an adult-like voicing contrast by age two, although striking individual differences may occur (Macken & Barton,1980).

Snow (1997) observed that the main individual difference found between children who acquired the contrast early and those that didn't, was their age at the time they had an expressive vocabulary of 30 to 70 words (subject's age ranged from 1;6 to two years). Children who had reached the criteria close to their first birthday acquired the VOT-contrast quite early relative to linguistic milestones such as the onset of syntax. Snow (1997) argued that it seems that when children's lexical development was advanced, their relative acquisition of VOT was also accelerated. Macken and Barton (1980) are the only other researchers which made an observation that may support this notion of Snow (1997), and interestingly, they studied children in more or less the same age range. Macken and Barton (1980) observed that the only child in their study (subjects ranged from 1;4 to 2;4 years), who produced all three stop pairs (of English) in an adult-like manner, was the subject with the biggest vocabulary. These are interesting observations but more investigation of the issue is needed before conclusions can be reached. No other studies that related subjects' linguistic development to their VOT-development were identified.

2.5.1.1.2. Development of VOT after two years of age

Although disagreement exists as to the exact age at which the voicing contrast is acquired, most English-speaking children seem to have developed it by approximately 2;6 years (Kewley-Port & Preston,1974; Macken & Barton,1980). Gilbert (1977) found that around average three years of age, English-speaking children were more or less producing the adult model for voiced, alveolar [d], while still producing phonetic variants of the voiceless, alveolar [t], which did not conform to adult values but yet were perfectly acceptable and recognizable instances of the intended phone. This may indicate that the child aged three, although perceptually capable of producing a voicing contrast, has not yet achieved the complex articulation necessary for its realization in the adult mode (Gilbert,1977). Based on this observation Macken and Barton (1980) emphasized the fact that as the judgements of adults may not capture significant facts about the child's system, spectrographic analysis is needed in addition to perceptual judgements, in order to provide more insight in these areas.

Based on studies of 2;6 to six-year-old children, it appears that once a distinct voicing contrast is acquired, further occurring VOT-changes may reflect refining of motor control and thus of phonetic detail (Macken & Barton,1980; Gilbert,1977; Zlatin & Koenigsknecht,1976). It may be several months or even

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

years before children acquire sufficient articulatory skill to constantly produce adult-like voicing (Macken & Barton,1980). English-speaking children aged two to six-years old, show a restricted range of the continuum for production of voiced stops, which contrasts with the VOT-distribution for voiceless stops which is relatively flat and widespread (Zlatin & Koenigsknecht,1974). From 2;6 to six-years of age, the long-lag VOT-range for voiceless stops narrows continuously, resulting in decreased variability (Zlatin & Koenigsknecht,1976). The range of long-lag values for voiceless stops is considerably larger than the adult range even at six years, and its only after age six that two distinct non-overlapping VOT-ranges are established for English (Zlatin & Koenigsknecht,1976).

At about six years of age, VOT-distributions for English-speaking children are then generally bimodal, but the ranges of values for voiced and voiceless stops overlap to a greater degree than for adults (Kent,1976). Development of the voicing contrast in English seems to be reflected by movement from the primary mode to the longer lag region of the VOT-continuum. Lisker and Abramson (1964) noted that in the phonetic realization of phonemic contrasts, human beings fall considerably short of utilizing all the phonetic space that is available to them. Zlatin & Koenigsknecht (1974:107) argued on this basis that "The unstable, infrequent occurrences of lead in production of voiced stops and long lag in production of voiceless stops during this early period, reflect children's exploration of 'phonetic space' as well as a lack of consistent control over the timing of laryngeal and supralaryngeal articulatory events.".

Eventually, VOT-values show a distinct bimodal distribution characterized by little or no overlap of the values for voiced and voiceless stops. Voicing lead (negative values of VOT, for which voicing precedes articulatory release) in English becomes more common with maturation, especially for bilabials (Kent,1976). Variability of VOT also decreases with age, so that adult stability of production is noted at about eight years of age (Kewley-Port & Preston,1974; Zlatin & Koenigsknecht,1976; Kent,1976; Smith,1978). Hawkins (1979) however, found that VOT for long-lag English stops is not completely mature even up to eight years of age, since it was poorly controlled both in terms of mean absolute duration and of precision over several repetitions.

2.5.1.2. Factors that may influence VOT

In addition to studies focussing on general developmental trends in VOT-acquisition, a few studies also investigated if and how different factors influence VOT-values in children. Such information is important when interpretations of VOT-results have to be made, since it may explain and clarify observations and give indications as to the generalization value of results.

Bond and Korte (1983:a) examined the effect of *mode of elicitation* (spontaneous versus imitatively elicited) in children aged two to 3;8 years and found no differences in VOT between words produced spontaneously and those produced imitatively. Beardsley and Cullinan (1987) studied the effect of *sample type* on VOT in children (ten children aged five years), using repeated utterances of isolated meaningful CVC-words, isolated nonsense CVC-syllables and meaningful words. Firstly, they found in correspondence with Zlatin and Koenigsknecht (1976) longer VOT's for voiceless stop [p] than for the voiced stop [b]. The magnitude of [b]-[p] differences were found to decrease as the condition changed from nonsense syllables, to meaningful syllables in isolation, to meaningful utterances in a phrase. Thus, voicing leads for [b] were most common in the nonsense syllables, less so for the meaningful syllables in isolation and rarely occurred for the meaningful syllables in the carrier phrase. VOT's for [p] and [k] differed significantly for meaningful syllables but not for nonsense syllables. Beardsley and Cullinan (1987) cautioned that until further studies on the effect of sample type on VOT have been completed, investigators should be careful not to generalize findings from studies using isolated nonsense words to spontaneous speech.

It appears from research that certain *sound effects* may also influence the development of VOT. The control of VOT in *alveolar* stops seems to be more difficult for children than that of *labial* stops. As previously described, infrequent

UNIVERSITEIT VAN PRETORIA
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YUNIBESITHI YA PRETORIA

voicing lead occur in the VOT-values of two to three-year-olds. However, it was found that voicing lead, when present, was evidenced more often in association with bilabial stops (Preston & Yeni-Komshian,1967; Smith,1978) than with alveolar and velar stop productions (Zlatin & Koenigsknecht,1976). Certain physiological factors, such as the presence of a larger available supraglottal cavity, less mechanical pressure, a reduction in intra-oral pressure and greater potential for some degree of velopharyngeal opening, can contribute to an increase in transglottal pressure drop, which may facilitate initiation and maintenance of voicing for labials in contrast with alveolar and velar stops (Zlatin & Koenigsknecht,1974).

Further, an ***inter-place relationship*** exists in adult productions of VOT, where VOT increases for voicing-lag stops (by +20ms to +25ms), as one proceeds from an anterior to a posterior oral occlusion (Lisker & Abramson,1964). Zlatin and Koenigsknecht (1974) observed the same place relationship in voiced stops for two and six-year-old English-speaking children, since VOT lag-times for voiced stops increased from [b] to [d] to [g].

It is obvious from this summary that VOT-results have to be carefully interpreted, and that possible influential factors need to be considered in research. Results obtained in VOT-studies can thus not be widely generalized and the applicability of results is restricted to some extent in terms of factors such as language, the specific material used and the mode of elicitation.

2.5.2 DEVELOPMENT OF SEGMENTAL DURATION

As previously described, speech itself has many temporal characteristics which can be perceived acoustically, for example speaking rate, and word and segmental duration. In 1976, Kent observed that "Other than VOT, temporal aspects of speech production have received scant attention in developmental studies. This neglect is unfortunate because timing may be the most critical factor in skilled motor performance." (Kent,1976:483). It seems as if his observation was taken to heart by subsequent researchers, since a shift in attention occurred in studies of speech development after the late seventies. Research seemed to have gradually moved away from a concentration on VOT, to a more intensive focus on other aspects of speech motor development such as word and segment duration.

2.5.2.1. General developmental aspects of timing control in speech production

DiSimoni (1974:a;b;c) did pioneer work in the study of the development of temporal aspects of speech development, even before Kent's (1976) observation. DiSimoni (1974:c) for example investigated *segmental duration* of repeated productions of [s] in the productions of children aged three, six and nine. He found that segmental durations decreased with age, thus, older children had articulated more rapidly or had faster rates of speech. Overall DiSimoni's research showed evidence of an increasingly accurate timing mechanism (DiSimoni,1974:c). Several subsequent acoustic and kinematic studies found accordingly that children spoke *more slowly* than adults, and that segmental duration overall *decreases* with age (e.g. Smith,1978; Kent & Forner,1980; Kubaska & Keating,1981; Smith et al.,1983; Rimac & Smith,1984); Chermak & Schneiderman,1986; Walker, Archibald, Cherniak & Fish,1992; Smith & Kenney,1998). In spite of occasionally reported *individual differences* and sometimes *context-specific* age-related findings, the overall consensus in the literature still is that children speak more slowly than adults and that a decrease in duration and an increase in speaking rate occur with age (Walker et al.,1992; Smith et al.,1995). The exact reason for this, however, remains debatable.

Smith (1978) suggested that the observed tendency of word and segment duration to be inversely correlated with age, probably is a function of *increases in neuromuscular control*, which occurs during the first 15 to 20 years of life. Myelination of motor neurons for example, may be a important factor involved in observed increases in rate of motor performance as children get older (Smith, 1978). "Unmyelinated neurons have a long tendency, are slow firing, and fatigue early, whereas myelinated neurons have a short latency, fire rapidly and

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

continuously, and have a long period of activity before fatiguing." (Crelin in Smith,1978:60). Some explanations or hypotheses currently offered for children's general slower speech movements and/or longer segmental durations than those of adults, thus include the possibility that it may be the consequence of *neuromuscular immaturity* (Kent,1976; Smith,1978; Netsell,1986). In addition, it may also be the result of *less skill* and experience in "...*planning* and *organizing* sequences of speech gestures." (Smith & McLean-Muse,1987:752). Conclusive explanations for slower timing aspects in children's speech have not been formulated and await further exploration.

2.5.2.2. Factors that may influence timing control of speech production in children

In addition to determining general developmental trends of speech timing control, researchers also aimed to identify *factors* that might influence timing control in children's speech. As in adult sensorimotor speech control, the child's ability to adapt spatial and temporal aspects of speech production to the context of production is a very important speech production skill, since speech production is "...context sensitive..." (Van der Merwe,1997:6). Information about how certain factors affect children's speech timing control, may yield insight into sensorimotor speech control processes such as planning, programming and execution. Further, this information is important to consider when interpretations of speech timing control research results have to be made, since it identifies possible causative contextual factors that can be considered in the explanation and clarification of observations.

In addition to performing pioneer work in the investigation of general developmental aspects of timing control, DiSimoni (1974:a;b;c) was also one of the first researchers to investigate *contextual* effects on segmental duration. Several subsequent researchers continued to investigate and expand his observations. The extensive study of Smith (1978) for example, made a huge contribution to understanding the influence of contextual effects on children's timing of speech production.

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2.5.2.2.1. The effect of vowel environment on segmental duration

DiSimoni (1974:a) examined the effect of vowel environment on consonant duration in children ages three, six and nine years old respectively based on the findings of Schwartz (1969). Schwartz (1969) found that consonant duration in adults were significantly lengthened when the final vowel was a [i] (e.g. [isi]), regardless of what the initial vowels were. Schwartz (1969) reasoned that the primary effect on duration of the consonant element in a VCV-utterance was caused by the relative tongue positions between the consonant and the final vowel, and that the effects of the initial vowel were negligible. On this basis he posited the existence of ***a foreward scanning*** or ***anticipatory mechanism*** at work in coarticulatory behavior. DiSimoni (1974:a) found that this effect of vowel environment on consonant duration previously noted for adults, was not significantly present in the speech of three, six and nine-year-old children, although it nearly reached significance in the nine-year-old group. Though the differences in duration of [s] in [i] and [ɑ]-environments were not significant, it was noted that durations for [s] were greater in a final [i] environment than it was in a final [ɑ] environment for almost all subjects of each age group. DiSimoni (1974:a) concluded that the spatial compensation task described by Schwartz (1969) was not present in the speech of children as old as nine-years of age. He argued that the results did not necessarily contradict the possibility of the presence of an active 'scanning ahead' mechanism in the speech of children, but that the data suggested that if such a mechanism is active in children, it is not yet functioning in the manner assumed for adults. DiSimoni (1974:a:361) presented two hypotheses to explain this difference. Firstly, he argued that it is possible that "...even by age nine, the system has not yet developed to the level of operating efficiency assumed for adults..." and secondly, that "...because children have smaller orofacial structures and thus smaller spatial differences between vowels than adults, the expected differences between vowels would simply not be as great.". Unfortunately, no comparative study could be found that replicated the exact aims of DiSimoni's specific study.

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YUNIBESITHI YA PRETORIA

2.5.2.2.2. The effect of utterance length on segmental duration

DiSimoni (1974:b) examined the effect of *utterance length* on speech timing control, as Schwartz (1972) and Lindblom (1968) have shown that in utterance length of mature speakers, both consonant duration and vowel duration are decreased as the overall length of an utterance is increased. In DiSimoni's study the presence of the effect of decreased duration of phonemes due to increased length of utterance, occurred only in the six and nine-year-old groups, indicating that phoneme duration conditioning effects are not present in the speech of three-year-olds, but appear between three and six years of age. DiSimoni (1974:b) theorized that a chronological sequence of development of durational control systems might exist, which suggests the possibility of a hierarchy of coarticulatory functions. With respect to the effect of utterance length on speaking rate, Amster (in Walker et al.,1992) also found a relationship between length of utterance and speaking rate for children between the ages of 2;6 and 2;11 years and for boys between 3;6 and 3;11 years, the latter indicating a possible gender factor. Existing evidence about a relationship between gender and rate of utterance is presently inconclusive due to ambiguous findings (Walker et al.,1992).

2.5.2.2.3. The effect of place of articulation on segmental duration

Smith (1978) found that for all the groups in his study (two, four-year-olds, and adults), the duration of *bilabial [b]* was significantly longer than that of *dental [d],* although no inter-group relative or absolute differences occurred. Smith (1978:41) argued that results suggested that this difference may be attributed to "...biomechanical aspects of the production mechanism..." and perhaps that "...the greater tissue mass involved in labials causes them to have greater inertia and thus, facilitates the slight differences in timing.". Further evidence from MacNeilage (1972) that this effect is context-free in adults, also suggests that it may be an inherent durational property of bilabial productions, rather than indicating a more complex planning process for bilabials than for dentals.

Kuijpers (1993) found that although no differences occurred between four and six year-olds' durations of [p] and [t], the closure duration for [k] was clearly shorter in the speech of the *younger* children. She attributed this firstly to a possible physiological explanation, claiming that [k] requires the least spatial accuracy. The posterior closure can be made almost anywhere and demands less accuracy (in terms of refinement, time and activity) than anterior closure (Kent & Moll in Kuijpers,1993). Physiologically, the obstruction for [k] also demands more activity of extrinsic tongue musculature than of intrinsic tongue musculature by comparison to [t] and it seems that in young children, extrinsic musculature are more developed and easier to use than intrinsic musculature (Kent,1981). Older children were not found to be influenced by these factors (Kuijpers,1993). A second explanation is the lack of contrast, because Dutch does not have a voiced cognate for [k]. Kuijpers (1993:325) argued that "It seems that the younger children would not necessarily have generalized a rule about voiceless stops that groups [k] together with [p] and [t].". Physiological, linguistic as well as *perceptual* factors should thus be taken into account in interpretations of durational data of speech motor development.

2.5.2.2.4. The effect of consonantal voicing on segmental duration

Results from adult studies suggested that closure duration differences exist between voiced and voiceless consonants, probably as a result of intrinsic, physical causes in the cases where such differences is less than the just noticeable difference for duration perception (i.e. between 10ms and 40ms, Lehiste,1970: 13). In cases where this difference falls into the range of "possible perceptual salience", it may be "...intentionally produced to aid in distinguishing voiced and voiceless stops." (Smith,1978:42). Smith (1978) found that with the exception of flaps produced by the four-year-olds in his study, the duration of [d] for English-speaking children was longer than for adults "...by an increment probably attributable to differences in neuromotor control capability." (Smith,1978:61). However, in the case of [t], both the four-year-olds and the two-year-olds produced [t]'s which were about 40% longer than neuromuscular differences alone would have produced, indicating the presence of some other powerful cause

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

(Smith,1978). Smith (1978) offered both the *physiological* (production) and *perception-orientated* explanations for this finding, although he stressed that a conclusive explanation has not been reached. A physiological explanation that may have facilitated such durational differences, is the fact that the long closure duration for [t] may demand complex laryngeal adjustments in order to produce a voiceless, aspirated stop. On the other hand, children might have intentionally produced [t] "...with a relatively greater duration in order to more effectively distinguish it from [d]. " (Smith,1978:62).

2.5.2.2.5. Consonantal effects on segmental (vowel) duration

The "...conditioning of vowel length by the voicing of a following (final) consonant." (Smith,1978:42), has been noted in the speech of adults of different languages. The exact amount of *vowel lengthening* before a voiced consonant may vary between languages from 100ms longer in English to a 20ms to 30ms difference in Russian and Korean (Smith,1978). Naeser (1970) investigated the dependence of vowel duration on the voicing of the following obstruent and found that appropriate duration differences were present as early as 21 months of age. Naeser (1970) found that vowels before voiceless final consonants were approximately 50% to 60% the duration of vowels before voiced consonants, which corresponds well to reported adult values. Smith (1978) found in correspondence with Naeser (1970) that vowel duration for children was greater before *final voiced stops* than before *voiceless* ones. Further, even 2;5 to three-year-olds lengthened vowels before *final voiced* stops but not before *non-final* ones, thus showing possession of a *sensitive, complicated, timing system*.

In addition, Smith (1978) also investigated the effect of p*lace of consonant articulation* on vowel duration (i.e. vowel length) and found that vowel duration was greater before [d] than before [b] for both children and adults. Results also indicated very similar vowel and consonantal durational relationships for adults and children. For example, the segment [d] was shorter in duration than [b], but *vowels preceding [d]* were longer than vowels preceding [b]. Similarly [d] was shorter than [t], but *vowels before [d]* were longer than vowels before [t]

(Smith,1978). Thus, "...voiced labial stops are longer in duration than voiced dental stops, but vowels preceding labials are shorter in duration than those in the dental environment." (Smith,1978:63).

2.5.2.2.6. Effects of syllable position on segmental duration

Results of Smith (1978) indicated that in both children and adults, *final-syllable vowels* were longer in duration than non-final vowels. However, different percentages of lengthening occurred, as final vowels in [t]-words were only lengthened about 40%, while a figure of about 80% occurred for vowels in [b]- and [d]-words. Smith (1978:57) argued that this indicates the sophistication of children's speech timing control since "They could not have merely learned to increase final vowels by a single, fixed amount; they must at least be sensitive to contextual variables.".

Syllable position also affected *consonantal duration,* as in all cases, final consonants were longer than non-final consonants. For both relative and absolute differences the adults evidenced the shortest and the two-year-olds the longest durations. For all three age groups (two, four-year-olds and adults), [b] showed the smallest relative increment due to position and [t] the largest (Smith,1978).

Although not all languages show the phenomenon of final syllable lengthening to the same extent, Smith (1978) theorized that minimal final-syllable lengthening might occur universally in languages because of physical level production principles. "Final syllable lengthening might be a natural aspect of production. Those languages exhibiting little lengthening might be constrained by language-specific timing characteristics that counteract lengthening."(Smith, 1978:64).

2.5.2.2.7. The effect of stress on segmental duration

Adult data indicated that stressed vowels in English are anything between 50% to 90% longer in duration than unstressed vowels (Smith,1978), and that it may be due to learned, linguistic factors. The effect of stress appears to be a language-

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specific phenomenon as in languages such as Estonian, unstressed syllables may be longer than stressed ones (Lehiste in Smith,1978). Smith (1978) examined the effect of *stress* on duration in English children aged four to six-years-old, and found that stressed vowels for all three groups (adults included) were 20% to 30% longer in duration than unstressed vowels in all three consonant environments. No obvious developmental trends were evident and more longitudinal data are needed in this area (Smith,1978).

2.5.2.2.8. The effect of sample type on duration

Kubaska and Keating (1981) investigated another contextual variable, *word familiarity*, by determining whether it contributed to shortening of word duration in the speech of children aged 16 months to three years. They found no such relationship and concluded that the fact that word duration decreased with age, cannot be attributed to an increased familiarity with individual lexical items. Their results did indicate however, that word duration variations within the tested time ranges appeared to be largely attributable to the effect of *position in utterance*. Isolated and utterance final tokens (words) were longer than non-final tokens. They argued that average word duration might decrease as a child grows older, partly because a larger percentage of word tokens appears in non-final position. Although no replication of the aims of this study was found for the sake of comparison, this observation should be considered in longitudinal studies of durational aspects of early speech motor development.

Beardsley and Cullinan (1987) investigated the influence of *meaningfulness* on segmental duration in five-year-olds' repeated utterances of isolated meaningful CVC-words, isolated nonsense CVC-syllables and meaningful words with a carrier phrase. Beardsley and Cullinan (1987) found meaningful syllables in isolation to be significantly longer in duration than corresponding syllables in the carrier phrase. For three of the four meaningful syllables, vowel durations were shorter and final stop consonant closure durations were longer for the syllables in the phrase, than those in isolation. For all four meaningful syllables the vowel duration constituted a smaller proportion and the closure duration a larger proportion of the overall syllable duration for the syllable in the phrase than in

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isolation. The vowel duration constituted a larger proportion and the final stop consonant closure a smaller proportion of the overall syllable duration for the meaningful syllables "pig" and "big" in isolation, than for the nonsense syllables "pog" and "bog". They concluded that differences in speech sampling type affect certain segment durations and relationships between various segment durations in the speech of children. The effect, however, on intra-subject segmental duration variability was low (Beardsley & Cullinan,1987).

A recent study of Robb and Tyler (1995), although conducted with much younger subjects, corresponds to some extent to Beardsley and Cullinan's (1987) findings, and expands on the possible influence of m*eaningfulness* on durational aspects. Robb and Tyler (1995) examined the developmental relationship between the durations of real words and non-words in young children between eight and 26 months of age. They found that real-word duration significantly decreased as a function of increasing chronological age, while non-word duration was not correlated with increasing age. They suggested that because of the meaningfulness associated with real words, the articulatory gestures required of such forms might be more constrained than those of non-words Robb and Tyler (1995:1352) stated that "This articulatory constraint is depicted.... in the form of less CV-word duration variability than CV non-word durations... as a function of chronological age as well as a gradual reduction in word duration with increasing age.". They also found indications that children's entrance into the multiword utterance stage (24 to 26 months), may be marked by a period of instability in real-word durations. Due to limited data on the subject in older children, it is difficult to generalize these findings. However, these results do suggest that investigators should also be sensitive to the possible effect of meaningfulness.

2.5.2.2.9. The effect of elicitation mode on segmental duration

Walker et al. (1992) examined how speaking rate is influenced by *spontaneous* versus *imitative* speech contexts. They found faster speaking rates in spontaneous speech conditions as compared to imitated speech across age groups. However, when linguistic complexity was controlled (by asking subjects to imitate two

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utterances previously spoken in spontaneous speech), no differences between the two contexts occurred.

2.5.2.2.10. The effect of performance level on segmental duration

Smith et al. (1983) observed that although children's segment durations were typically longer than those of adults at normal speaking rates, it appeared as if these age-related differences may be even greater at fast speaking rates. They found that children ranging from five to nine years of age, exhibited sentence durations that were 36% longer than those of adults when both groups were speaking at fast rates, while the children's durations were only 25% greater at normal speaking rates. Rimac and Smith (1984:388) argued that "It appears that speech segment durations may be affected to a greater extent when children are required to perform at maximal vs. sub-maximal levels.". In the light of this argument, the 'effort level' at which the child is required to perform (e.g. maximum vs. normal speaking rates), can also be considered a contextual influence on speech production (Van der Merwe,1997).

2.5.2.2.11. The effect of intrinsically short and/or long segment types on duration

Rimac and Smith (1984:388) theorized that if durational differences between children's and adults' speech are greater for maximal speaking rates, it is possible that their "...durations differ by varying amounts at normal speaking rates as a function of intrinsic durational characteristics of specific segments. That is, children may produce inherently longer segments with more adult-like durations, whereas inherent shorter segments may be more demanding on children's speech motor capabilities and may therefore, be produced with less adult-like durations.". Based on their hypothesis, Rimac and Smith (1984) compared children's productions (children aged 7;9 and 8;5 years) of segments with inherently short durations (i.e. flaps), with segments having inherently longer durations (i.e. stressed vowels). (Flaps or flap-like productions occur in American English when [t] and [d] follow a stressed vowel and precede an unstressed one). Their findings indicated that relative comparison of children's and adults' speech

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segment durations should be considered carefully in research. Relative comparison seemed to indicate that the children's production of segments that were intrinsically longer in duration were more adult-like than segments that were intrinsically shorter in duration. This was interpreted to be a mathematical artifact, however, as the results of the absolute comparison suggested that the children did *not* produce intrinsically short segments in any less of an adult-like way, than they do inherently longer segments. Absolute comparison determined that all segment types (including flaps) produced by the children were approximately 25ms longer in duration than those of adults. In summary, these results thus indicated that children's speech motor control capabilities show quite *uniform temporal effects* for all segment types, regardless of whether they were intrinsically short or long.

2.5.3. VARIABILITY IN CHILDREN'S SPEECH MOTOR CONTROL

The phenomenon of token-to-token *variability* of speech movements has been observed across different studies of speech motor development through the years, and is today generally considered to be characteristic of children's speech movements (Smith et al.,1995). Two basic assumptions regarding variability of children's speech movements are maintained. Firstly, it is recognized that children's speech movements are *more variable* than those of adults, (e.g. it evidences a greater range of durations over repeated productions of a particular utterance) and secondly, it is generally agreed that with development from childhood to young adulthood, variability of speech production *decreases* (e.g. Eguchi & Hirsh,1969; DiSimoni,1974:a;b;c; Tingley & Allen,1975; Kent,1976; Smith,1978; Kubaska & Keating,1981; Smith et al.,1983; Hawkins,1984; Sharkey & Folkins,1985; Chermak & Schneiderman,1986; Smith,1992; Smith,1994; Smith,1995; Smith et al.,1995).

It should be mentioned that in spite of these two general notions regarding the concept of variability in children's speech movements, many of these researchers mentioned cases of very *individual* trends in performance (e.g. Kent &

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Forner,1980; Walker et al.,1992; Smith & Kenney,1998). In addition, through the years the possibility was raised that variability in speech motor control processes may be influenced by aspects such as *different phonetic contexts* (e.g. Kent & Forner,1980), *word familiarity* (Schwartz in Smith,1992), the *type* of sensorimotor speech control *parameter* measured (e.g. Kent & Forner, 1980; Sharkey & Folkins,1985), that variability may vary between individual *articulators* such as the lip and jaw for example (e.g. Sharkey & Folkins,1985; Nittrouer,1993; Smith,1995) and also between *articulatory subsystems* studied e.g. laryngeal vs. respiratory system (Stathopoulos,1995). Further, Allen (in Smith, 1992) noted that even factors as diverse as *biomechanical properties of the articulators* (e.g. tissue elasticity) and possible *electrochemical properties* of the brain are likely to contribute to a speaker's variability in production.

Unfortunately, the exact nature and role of these factors in terms of variability in sensorimotor control processes are only beginning to be studied and conclusive facts and explanations are not yet available. Increased understanding of the nature and characteristics of variability in speech movements, and what it indicates regarding normal (and abnormal) speech motor control development will only be possible with an increased number of studies. Any study of normal (and abnormal) sensorimotor speech control has to determine if variability of temporal and/or spatial aspects of speech movements are present in the data, and if so, should try to explain what it possibly indicates in terms of sensorimotor speech control processes. Extensive research in this area is still needed.

In spite of the general agreement regarding the fact that variability is characteristic of children's repeated speech movements and that it decreases with increased age, conflicting interpretations exist as to *why* this is the case and what "...token-to-token variability of movement parameters relative to the processes of speech motor development." (Sharkey & Folkins,1985:9) indicates or reflects. Smith (1992:2166) aptly noted that "As is commonly the case when studying speech production in children or adults, the answers concerning such issues are ultimately likely to be much more complex that is implied by the rather straightforward questions that are often asked.". These different interpretations will be briefly summarized, since examiners have to be aware of different clarifying hypotheses when considering the implication of research results regarding variability. Presently, not enough research data exist to either favor or reject any of these hypotheses conclusively.

2.5.3.1. Variability-as-error perspective

Some researchers (e.g. Tingley & Allen,1975; Kent,1976; Smith 1992) have interpreted the decline in children's variability of speech movements with age, as a sign of increased skill development (based on Bruner's 1973 theory of motor skill acquisition). In addition, they have equated the observed variability in children's speech movements with "movement imprecision error" (Sharkey & Folkins,1985:8). This approach implies that as the child's sensorimotor speech control skills develop, certain "...best movement patterns..." are "...refined from a repertoire of less efficient ones." (Sharkey & Folkins,1985:8), resulting in increased precision. From such a viewpoint variability of speech movements is thus the direct result of imprecise articulatory movements and a reflection of immature speech movements.

2.5.3.2. Variability-as-flexibility perspective

Bernstein (1967) has developed a theory of motor skill acquisition that stresses that regardless of the level of skilled development, multiple repetitions of other motor tasks are seldom repeated with the same movement parameters. Bernstein (1967) argued that motor tasks may employ sets of coordinative structures which may produce many "...functionally equivalent movement patterns..." (Sharkey & Folkins,1985:8). With increased skill the child may thus learn new ways (e.g. through 'better' structural organization) to utilize his/her coordinative structure organization to accomplish the task. Based on such a view, variability in children's speech movements can be taken as an indication of *increased motor skill* and not necessarily as a reflection of imprecision or error. Even in cases where token-to-token variability was found to decrease as a motor system develops (e.g. Purves & Lichtman in Sharkey & Folkins,1985), it still may only

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be a reflection of a decrease in *flexibility* rather than refinement of precision (Sharkey & Folkins,1985). It has also been proposed that movement patterns for a task initially may be consistent, as they "...evolved from the relatively rigid primitive patterns and would slowly become more variable as the child improved control and exploits the ability to fit motor patterns to variations in then specific needs of the task." (Sharkey & Folkins,1985:9).

2.5.3.3. Variability-as-learning facilitation perspective

It has been shown that hand positioning for example, is learned more accurately when practiced at a variety of positions (e.g. Moxley in Sharkey & Folkins,1985). From such a perspective variability of speech movement patterns may play an *exploratory role* that aids motor learning (Sharkey & Folkins,1985).

2.5.3.4. The relationship between duration and variability of speech movements

Through the years the question of the *relationship* between the variables duration and variability of speech movements was also investigated, in order to determine whether the two concepts are closely related, or if they can be considered reflections of different aspects of sensorimotor speech control. The nature of this relationship needs to be clearly established in order to plan research, interpret results and generalize findings regarding duration and variability of sensorimotor control aspects.

Kent and Forner (1980) hypothesized that at least *part* of the variance in the duration measures they observed in children (four, six and 12-years-old) in their study, may have been related to speaking rate, given that speaking rate determines segment durations. They argued that "The younger children had slower speaking rates (hence longer segment durations) and therefore a greater variability, both as a group as well as individually." (Kent & Forner,1980:164). This led them to caution examiners of what can be called the *statistical artifact hypothesis*. They postulated that "When variability of timing is used to describe

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developing or disordered speech, it is important to recognize the possibility that increased variability may be related simply to a lower speaking rate (hence longer segments) and not necessarily to neuromotor immaturity." (Kent & Forner, 1980:167).

However, the statistical artifact hypothesis has been proven *unlikely* in various subsequent studies. Smith (1992) re-examined data from Smith (1978) and Smith et al. (1983), by shifting attention to the nature of the relationship between variability and duration. Smith (1992:2171) came to the conclusion that it is firstly, incorrect to assume that variability and duration develop "...in tandem..." and presumably provide comparable information about children's speech motor control and secondly, that variability in children's speech is *not* a mere *function* of duration. According to Smith (1992) his findings suggest that it may be possible to draw at least some conclusions about the speech motor control development of individual children on the basis of duration and/or variability. He cautioned though, that "...these two measures are not always closely related and, therefore, do not necessarily lead to similar conclusions about speech motor control." (Smith,1992:2171). Both may be meaningful measures, with each possibly indicating something about different aspects of neuromotor development for speech production. Smith (1992;1994) also suggested that it appears as if *duration* tends to reach adult-like levels earlier in the process of development than *variability*, but more conclusive evidence for such speculation is needed. This perspective implies that both durational and variability aspects of speech movement control need to be studied, since they possibly reflect different aspects of speech motor development.

Recently Stathopoulos (1995) voiced an opposing opinion regarding the meaningfulness of a measure such as variability in studies of sensorimotor speech control. According to Stathopoulos (1995:67), the issue regarding variability is "...by no means clear-cut.". She argued that firstly, a review of kinematic and acoustic literature failed to provide "...unequivocal support for the general assumption that the child's speech mechanism is more variable than the adults." (Stathopoulos,1995:67). However, Stathopoulos (1995) based this assumption

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mostly on the fact that researchers sometimes noted individual trends in performance that did not conform to general age group trends. Based on the previous overview of the various factors that could possibly be influential in the phenomenon of variability of speech movements, Stathopoulos' interpretation seem to ignore these factors, and her view can thus be considered very limited. Smith and Kenney (1998) for example, stressed the possible *individual nature* of speech motor development.

Secondly, Stathopoulos (1995) made several acoustic and kinematic measures on three repetitions of [pa] in children aged four, six, eight, 10 and 12-years-old as well as adults. She found that there were "...significant variability differences for some measures between children and adults, and that it was primarily the 4-year olds who accounted for the increased variability. Of the fifteen measures made, 4-year-olds were significantly more variable than adults on only eight. And on one measure, lung volume termination, 4-, 6-, and 8-year olds were significantly less variable than the adults." (Stathopoulos,1995:74). Based on these results Stathopoulos (1995) concluded that the children were not consistently more variable than adults. She stated that "A more reasonable interpretation would be that measures of variability are not a reliable indicator of motor speech maturity, and by inference, not a reliable indicator of neuromuscular maturity." (Stathopoulos,1995:77). In summary, Stathoupolos (1995) thus did find indications of variability, but not across all measurements. This is not surprising based on speculations that variability of speech movements may differ across speech subsystems and parameters (e.g. Sharkey & Folkins,1985). These findings are further difficult to compare to those of other studies, due to the different measurements made and the small number of repetitions elicited. Stathopoulos also used only three syllable repetitions where other research used at least five repetitions (e.g. DiSimoni,1974:c; Smith,1995) and even a number of repetitions up to 10 and 15 (e.g. DiSimoni,1974:b; Smith et al.,1983; Smith,1992) and 30 (Sharkey & Folkins,1985). Although not confirmed, it can be argued that more than three repetitions may more likely reflect instances of variability of speech movements. At this stage, Stathopoulos' interpretations regarding variability in speech movements appear contrary to the majority of those of other related

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studies. More information regarding the nature of variability across different speech parameters, and articulatory subsystems for example, is needed in order to reach a conclusion about the implications of her findings.

It can be concluded that more research is needed in the area of variability in speech production in order to determine the implications of different findings, speculations and hypotheses. Smith (1992:2172) summarized the complexity of the role of influential factors on variability by stating that "It is difficult enough to accurately specify how these (and other) factors interact and which are most likely to contribute to a speaker's variability when just considering normal adults, and the task is even more complicated when attempting to understand how such factors may interact to account for the greater variability often observed in young children's speech versus the speech of older children and adults.".

2.5.4. DEVELOPMENT OF COORDINATION AND COARTICULATION

Data on developmental aspects of *coarticulation* and speech gesture *coordination* are relatively scarce, diverse and complicated in nature, with conclusions that can only be called preliminary. During the 70's and 80's there seemed to have existed the general notion that children coarticulated 'less' than adults (e.g. Kent,1983). More in depth investigation, however, revealed that the coarticulation and/or coordination of speech movements in children, is a complex subject with different sides and influenced by a variety of factors. Repp (1986:1618) aptly cautioned that "....phenomena commonly clumped together under the heading of 'coarticulation' may have diverse origins and hence different roles in speech development.". The diverse nature of existing studies in terms of subject age, material used, instruments used, measurements made, different statistics conducted and aspects of coarticulation and/or coordination focused on, certainly emphasizes this reason for caution.

However, results of these studies, although diverse in nature, cannot be ignored since it contributes to our general knowledge of sensorimotor speech control

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development from a different perspective. For example, as previously described, the "...concept of coarticulation assumes that speech sounds are influenced by the influence of contiguous phonemes..." (Sereno & Lieberman,1987:247). An interesting aspect of these coarticulatory influences (especially anticipatory coarticulation), is that explanations for these results extend beyond simple "inertia" (Sereno & Lieberman,1987:247) factors. Anticipatory coarticulation for example, may reflect planning aspects of speech motor control (Kent,1983). In addition, adapting a phone to the articulatory features of an upcoming phone/s, might lead to greater speed and/or efficiency (Lindblom in Flege,1988), both of which are by some as indices of increased motor skill (e.g. Bruner,1973). Since we are only standing on the brink of uncovering the mysteries of how children develop sensorimotor speech control, all information on the subject need to be considered in formulating hypotheses and explanations for research observations. The results of major studies in the area of coordination and coarticulation are summarized in Table 2.6.

When reviewing the results from Table 2.6. there can be concluded that "Much as the fabled blind men each reported different descriptions of an elephant, depending on what part of the animal he touched, previous studies of the development of gestural patterns may each have reported different descriptions of this process, depending on what aspect of production was being examined." (Nittrouer,1993:970). Children's coarticulation and/or coordination of articulatory movements have been investigated with a variety of measures (all of which reflect vocal-tract activity to varying extents), different articulatory gestures were examined (e.g. labial vs. lingual coordination), and the material varied (e.g. phonetic composition, utterance length and thus complexity, clustered contexts vs. non-clustered). The divergent and sometimes contradictory accounts of age-related differences regarding coordination and/or coarticulation of articulatory gestures may thus be the direct result of differences in methods and as such, each study may reveal different aspects of what can be called "gestural patterning" (Nittrouer,1993:959).

TABLE 2.6: SUMMARY OF STUDIES ON COARTICULATION AND COORDINATION IN CHILDREN

Researchers	Subjects and Language	Material	Measurement Instruments	Measurements	Aspects of Speech Motor Development	Summary of Major Results / Conclusions
Watkin and Fromm (1984)	* Three children aged four, three aged seven and two aged ten.	* Syllables were repeated five times within a carrier phrase ([hipip] [hæpæp] and [hapɑp]).	* Gauge transduction system	* Mid-saggital superior-inferior movements of the upper and lower lip.	* Labial coordination	* The development of labial coordination in children ages four, seven and ten is due primarily to the learning of new motor skills. These skills are acquired most rapidly between seven and ten years. * Although the amount of variability decreased with age, the control of the reciprocal actions of the upper and lower lips remained relatively constant. This suggests that the labial control mechanisms were similar for all subjects and the reduction in variability was therefore due to learning, with the most rapid period occurring within the age range of seven and 10 years of age.
Turnbaugh, Hoffman and Daniloff (1985)	* Three groups of five subjects each, aged three, five and adults. * American English	* Five repetitions each of stop-vowel-stop syllables containing consonants [b/d/g] and vowels [i/u].	* Spectrograph (spectrograms)	* Second formant of vowel (relative coarticulatory influence of the vowel upon the release of each consonant).	* Lingual-bilabial coarticulatory effects	* Vowel perturbations of F2 onset in stop-vowel contexts were the same for adults, three and five-year-olds. There was no indication in the data that children coordinated less than adults. Control of CV lingua-labial interaction (or co-production) was more adult-like at this stage of development than either formant frequencies or segmental durations. * The neuromotor antecedents of stop-vowel co-production may be developed earlier than either temporal control or other kinds of more language specific coarticulations.
Repp (1986)	* Two sisters aged 4;8 and 9;5 years and their father *American English	* Six words were produced five times each in a carrier phrase "I like a..." Words: "sea,sand, soup,tea,tan, tooth".	* Oscillograph	* Effects of vocalic context on voiceless interval durations * Effects of vocalic context on constriction noise spectra * Effect of vocalic context on [ə] formant frequencies.	* Development of anticipatory coarticulation	*Two articulatory effects in the temporal domain were shown by both children and the adult. [s]-noise durations were longest before [i] than before [ae] (maybe due to earlier release of the constriction preceding more open vowels), indicating the effect of the following vowel on [s] noise duration. Secondly, VOT were longer before [i] than before [ae], indicating vowel effect on VOT. These effects may have kinematic or aerodynamic causes that make them difficult to avoid at any age. *Changes in F2 of [ə], in anticipation of the later-occurring vowel were shown only by the older child and adult (reflecting possible differences in tongue body position) and was not prevented by an intervening alveolar consonant which also involves the tongue. This long-range anticipatory lingual coarticulation across an obstacle may be a skill that is required relatively late as a child gets acquainted with the fine details of spoken language, and can be considered 'planned'.Vocalic context-effect on F1-frequency was shown by the adult alone and may have reflected anticipatory adjustments in jaw elevation. *A lowered [s]-noise before rounded vowels such as [u] most likely reflected an effect of anticipatory lip rounding, although changes in tongue position could also have played a role. Such an effect was observed in the younger child but not in the older child and was reversed in the adult. Fricative-vowel coarticulation may thus decline with age. * Phenomena commonly clumped together under the heading of "coarticulation" may have diverse origin and hence different roles in speech development. Some forms of coarticulation may be an indication of advanced speech production skills, some may be signs of articulation immaturity, and yet others may be neither because they simply cannot be avoided. It may not be wise to draw conclusions about a general process called coarticulation from the study of a single effect.

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TABLE 2.6 (-CONTINUED): SUMMARY OF STUDIES ON COARTICULATION AND COORDINATION IN CHILDREN

Researchers	Subjects and Language	Material	Measurement Instruments	Measurements	Aspects of Speech Motor Development	Summary of Major Results / Conclusions
Sereno, Baum, Cameron Marean and Lieberman (1987)	*I. Acoustic Analysis* * Three seven-year-olds and four adults * American English	*I. Acoustic Analysis* * Five repetitions of each token: [si;su; ti;tu;ti;du]	*I. Acoustic Analysis* * Spectrograph (spectrograms & waveforms)	*I. Acoustic Analysis* * Formants and mean spectral peak values	* Developmental characteristics of anticipatory, labial coarticulation	* Results indicated that both children ages three, seven and adults demonstrated an acoustic effect of coarticulation of lip rounding. For both speaker groups consonants produced in the environment preceding [u] displayed significantly lower spectral energy peaks than those produced before [i], even at the onset of stop stimuli and 70ms prior to vowel onset for the fricative stimuli. More individual trends occurred in the children's data. Acoustic results supported the conclusion that children's utterances exhibited less precise, more variable coarticulatory effects than adult utterances. * Although robust acoustical effects were observable in the children's stimuli, it is not clear that those acoustic clues were always perceptually salient. It is possible that these acoustic manifestations are not those that provide listeners with coarticulatory cues. * Perceptual results suggested that anticipatory labial coarticulation may constitute a generalizable change beginning in unvoiced alveolar stops [t] and spreading to other consonants [d] and [s]. Results also indicated that children do not generalize coarticulation across all consonants, a result that is consistent with models of acquisition in which the child initially starts on a word-by-word, phoneme-by-phoneme basis and only later generalizes across phonetic features and classes of phonemes. * The realization of the motor programs that underlie anticipatory coarticulation is not innate. Even for lip rounding there are differences depending on the nature of the segmental elements involved. The results were consistent with a developmental process involving gradual acquisition and fine-tuning.
	II. Perceptual Analysis * Ten adult native speakers of English	*II. Perceptual Analysis* * Aperiodic portion was excised from each CV-stimuli.	*II. Perceptual Analysis* * Tape recorder, headphone, answer sheet.	*II. Perceptual Analysis* * Perceptual ratings of the aperiodic portions corresponding to the consonants, to determine whether the acoustic manifestations of coarticulation were perceptually salient to naïve listeners.		
Sereno and Lieberman (1987)	* 14 children ranging from 2;8 to 7;1 years and five adults * American English	* Three tokens each of the CV-syllables [ki] and [ka]	* Acoustic: waveform display. * Perceptual identification of absent [i] or [a] in a forced-choice paradigm.	* Mean spectral peak values	* Lingual coarticulation	* Acoustic analysis revealed that adult stimuli displayed consistent effects of anticipatory lingual coarticulation (systematic difference in the spectra of [k] preceding [a] vs. [k] preceding [i]). Children's stimuli showed more variable lingual coarticulatory effects. Whilst some of the children's spectra displayed the same pattern as the adults, a few of the children's spectra did not show these systematic differences between [k]-spectra preceding [a] compared to [i]. * The perceptual study showed that subjects were highly sensitive to the acoustic difference in the adult [ki] and [ka]-stimuli. Children's results showed less accurate vowel perception scores. * The speech of some children thus did not show the acoustic or perceptual effects of lingual coarticulation. No age correlation was found (it also wasn't the youngest children), indicating an ideosyncratic tendency and thus individual differences in the development of automatized speech motor control patterns.

TABLE 2.6. (-CONTINUED): SUMMARY OF STUDIES ON COARTICULATION AND COORDINATION IN CHILDREN

Researchers	Subjects and Language	Material	Measurement Instruments	Measurements	Aspects of Speech Motor Development	Summary of Major Results / Conclusions
Flege (1988)	* Three groups of ten subjects each. Mean ages: 5;9 and 10;9 years and adults. * American English	* Six syllables formed by inserting vowels [I; i; u] into consonant contexts [d_d]; [n_n]; [n_d]; [d_n] * Ten repetitions of each token said with a carrier phrase * Produced first at normal and then at a fast speaking rate.	* Accelerometers placed on nares and larynx and micro-phones ("a new acoustic method")	* Vowel duration * Duration of nasalization * Percentage of nasalization * Average nazalization of vowels * Frequency of occurrence of fully nazalized vowels.	* Anticipatory nasal coarticulation	*All three age groups began opening the velopharyngeal port (VPP) long before the lingual constriction for word-final [n]. No significant differences were found to exist between groups for vowels spoken in [d_n]-context. Duration of nasalization observed for adults, ten and five-year-olds differed little for speech produced at normal or fast speaking rate. This is consistent with the belief that the temporal extent of carry-over coarticulation is determined largely by inertial properties of the speech production mechanism, and that children do not need more time than adults to close the VPP after release of [n]-constriction. The lack of a significant difference between children and adults is consistent with the view that anticipatory nasal coarticulation is a "natural speech process". *Vowel identity exerted an important influence on the spectra of preceding consonants for young children as well as adults. *Findings were not consistent with the predictions generated by "look ahead" models of nasal coarticulation. VPP-opening would be expected to begin at the onset of vowels spoken in the context of [d_n] and VPP-closing to begin at the onset of vowels spoken in the context of [n_d]. However, 93% of vowels were not fully nazalized in the [d_n] context and 33% were fully nazalized in the [n_d] con-text. Data suggested that talkers may time VPP-opening to begin at the same relative time within the vowel interval. If so, VPP timing in [dVn] syllables should be regarded as "phase locked" rather than "time-locked". Data suggested that neither a fixed nor a relative timing strategy were used in producing the [nVd] syllables. *Multiple gestures needed for [n] were not synchronously timed in the speech of children or adults. No difference between adults and children in the temporal domain of nasal coarticulation was observed in [nVd]-syllables. The data are consistent with the belief that carry-over coarticulation depends on inertial properties of the speech production mechanism. No differences between adults and children were observed in the temporal domain of anticipatory nasal coarticulation in [dVn] syllables. This suggested that nazalizing vowels in [dVn] syllables is a natural speech process that need not be learned.
Nittrouer, Studdert-Kennedy and McGowan (1989)	* Eight adults and four groups of eight children each aged: three, four, five and seven years. * American English	* Ten tokens each of reduplicated syllables containing fricatives & vowels: [ʃiʃi]; [sisi]; [ʃuʃu]; [susu]	* Acoustic analyses (spectrograph)	*Centroids * Fricative F2 * Segment and syllable durations	* Organization and coarticulation of fricative-vowel syllables	**Fricative contrast:* Adults differentiated between fricatives more strongly than seven-year-olds and seven-year-olds more strongly than younger children. The age-related increase in fricative contrast might be primarily due to improved control over constriction shape. The younger children already executed constriction placement quite largely, and lip rounding entirely, in an adult fashion * *Fricative-vowel coarticulation:* Children showed rather strong fricative-vowel coarticulation. As children and adults did not differ in anticipatory lip rounding, the children's stronger fricative-vowel coarticulation must be due to greater overlap between their consonant and vowel gestures, that is, to greater fronting of the tongue body before [i] and greater backing of the tongue body before [u]. *They hypothesized that perceptual capacity is logically prior to and must lead productive capacity, but that the two perhaps are never far apart. They argued that at each point in language development "...we may suppose the child has the phonology that its perceptuomotor skills permit and assure." (p.131).

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TABLE 2.6 (-CONTINUED): SUMMARY OF STUDIES ON COARTICULATION AND COORDINATION IN CHILDREN

Researchers	Subjects and Language	Material	Measurement Instruments	Measurements	Aspects of Speech Motor Development	Summary of Major Results / Conclusions
Katz, Kripke and Tallal (1991) *(Three experiments combined into one study)*	*I. Acoustic Analysis:* * 30 children, ten in each age group aged three, five, eight, ten and adults. * American English	*I. Acoustic Analysis:* * Picture/ puppet naming of tokens "sue" and "C". * Eight repetitions of each token in a carrier phrase	*I. Acoustic Analysis:* * Oscilloscope (waveform) * Speech processing programs	*I. Acoustic Analysis:* * Segment durations * Fricative centroids * Fricative spectral peaks anticipating the second formant of the vowel.	* Development of timing and anticipatory and coarticulation in fricative-vowel productions	* The extent of anticipatory coarticulation was essentially adult-like in children as young as three years of age. This pattern did not conform to the theory that young children show greater obligatory coarticulation effects than older children. Rather, the data suggested that eight and five-year-olds children produced a degree of intrasyllabic coarticulation similar to that of adults. * Inconsistency between acoustic and perceptual results was noted only for the three-year-olds. Articulatory imprecision might have produced subtle versions of the acoustic effects noted in the speech of misarticulating children. * Although articulatory cues for three-year-olds appeared less perceptible than those of other age groups, the [sV]-productions of children and adults were essentially stable with respect to the magnitude and extent of anticipatory labial and lingual coarticulation. * The pattern of results did not support the notion that two to three-year-old children exhibit speech characteristics reflecting a predominantly syllable-based system of perceptuo-motor organization. Acoustic and video rather suggested that children as young as three-years-old plan speech much as older children and adults do. * Perceptual data either suggested that coarticulation is produced with less regularity at age three than at later ages, or that three-year-old children produce regular coarticulatory cues that are more difficult to perceive because of poorly produced fricatives. There was no evidence suggesting that three-year-old speakers produced a greater degree of coarticulatory cues than older speakers. * Findings suggested that coarticulation develops in a gradual manner as other motor properties of speech do. * The overall pattern of results fits the view that young children acquire basic sound sequence ability at an early age, and that anticipatory coarticulation is a fine-tuning of temporal information acquired gradually during maturation.
	II. Perceptual Analysis: * ten undergraduate listeners	*II. Perceptual Analysis:* * First five correct [si] and [su]-tokens produced by 34 speakers. The [s]-sound was excised	*II. Perceptual analysis:* * Earphones and answer sheets.	*II. Perceptual Analysis* * Extent to which listeners used coarticulatory information for vowel-context identification judgements		
	III. Video Analysis * ten undergraduate listeners	*II. Video Analysis:* * Three video edited images (frames) of lip-position in [si] and [su].	*III. Video Analysis:* * Video and answer sheet.	*III. Video Analysis:* * Extent to which listeners were able to use visual assessment of lip rounding (coarticulation) for vowel-context identification judgements.		

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TABLE 2.6. (-CONTINUED): SUMMARY OF STUDIES ON COARTICULATION AND COORDINATION IN CHILDREN

Researchers	Subjects and Language	Material	Measurement Instruments	Measurements	Aspects of Speech Motor Development	Summary of Major Results / Conclusions
Nittrouer (1993)	* Ten children aged three, five and seven respectively and ten adults. * American English	*Syllable sets consisting of stops [t;k;d] and vowels [ɑ;i;u] - presented with carrier phrase * Ten samples of each syllable were obtained	* CSpeech Software * Spectrograms and waveforms.	* Duration of schwa, stop closure, VOT and vowel. * Intra-subject variability (by coefficients of variation) * Formant frequencies	* Speech gesture organization and coordination. * Influence of specific articulator examined, linguistic compexity of utterances and phonemic composition on gestures.	* Children produced gestures similar in shape to those of adults, but many movements were produced more slowly by the children than adults, and with more temporal variability. * By age three to five years children were capable of producing the utterances in roughly the same sequence adults did. However, there was evidence that the rate with which mature gestural patterns were achieved, varied across articulators. Children appeared to acquire adult-like skill for jaw movements sooner than they did for tongue movements. *Even though children were producing syllables that were presumably well-practiced, two trends suggested that inter-gestural coordination had not reached mature status for the subjects in the study. First, consonant and vowel gestures overlapped longer in children's than in adult's samples. Although temporal measures of the two acoustic portions of the stressed syllable (VOT and vowel) indicated no significant differences between children and adult samples, the spectral analysis indicated that children took longer to move away from the consonant closure, and that they initiated the vowel gesture sooner. Secondly, there is some suggestion that that it was more difficult for children to initiate voicing after a devoicing gesture. Results seemed to have indicated that these children had not quite learned to coordinate in a mature manner either two supra-laryngeal gestures (i.e. tongue-tip release and tongue body backing) or a laryngeal-supra-laryngeal gesture (i.e. vocal fold adduction and stop release).
Nittrouer (1995)	* Ten adults * Ten three, five and seven year-olds resepctively	* 12 picture elicited real words with a CV-syllable structure containing the consonants [s] [ʃ] [t] [k] and vowels [ɑ/i/u]	* CSpeech Software used to compute spectral moments.	* Spectral moments	* Characteristics of articulatory gestures for fricatives and consonants.	* Children who had smaller oral cavities than adults demonstrated fricative and stop burst spectra that had higher mean frequencies than those of adults.[s] and [t] demonstrated spectra generally higher in frequency than [ʃ] and [k] *A significant difference between children and adults in the magnitude of vowel context effects were observed for [k]. Children's place of velar closure was more sensitive to anticipatory vowel production than that of adults. Tongue-body shape was found to be more greatly affected by upcoming vowel in children than in adults' samples. This difference was not found for [t], indicating that children's and adults' tongue-tip gestures were affected similarly by vowel context. *Adults differentiated their [s] and [ʃ] productions more strongly than children did. Children's fricative gestures were thus not as differentiated as those of adults (were found to be wider). * Stop-close gestures were the same for children and adults indicating that some articulatory gestures (namely stop-closure gestures) may reach mature status sooner than fricative gestures. This may be due to the fact that stops require complete closure of the vocal tract (thus providing clear feedback when the "target" had been obtained), with few requirements concerning tongue shape.

TABLE 2.6. (-CONTINUED): SUMMARY OF STUDIES ON COARTICULATION AND COORDINATION IN CHILDREN

Resear-chers	Subjects and Language	Material	Measure-ment Instru-ments	Measurements	Aspects of Speech Motor Develop-ment	Summary of Major Results / Conclusions
Hawkins (1973)	* Seven children aged four to seven * Adults * English	* Word initial and final clusters in English mono-syllabic words	* Oscillo-grams	* Segment durations (vowel and consonant durations)	* Temporal coordina-tion of consonant *clusters*	*Data indicated that there were some aspects of the timing relation ships within cluster consonants that tend to differ fairly consistently between children's and adult's speech, but that these differences were not invariant within or across subjects, nor did they show a convincing age trend. *Children tended to lengthen segments in clusters with initial fricatives e.g. [l]-lengthening in [sl]- There also was a significant tendency for postvocalic [l] to be longer before non-homorganic consonants of the same manner class. This was particular marked for fricatives but with stops it was only significant with the younger children. Results encouraged the idea that both pre- and postvocalic [l]-articulations are relatively more difficult for the child to coordinate than for the adult in a clustered context. * Children showed an increased period of aspiration of fricative-[r] in the homorganic cluster, which may have been the result of an effort to reduce the articulatory load. It seemed likely that the presence of pre- and post-vocalic [l] and possibly [s] in a cluster conditioned the largest and most interesting differences between adult and child patterns of modification.
Gilbert and Purves (1977)	* Five children in age groups: 5.0-5.6 years 7.0-7.6 years 9.0-9.6 years and five adults * Canadian English	* Meaningful, monosyllabic (CVC or CCVC-structure) word lists * Six non-consecutive tokens with a carrier phrase "Repeat.."	*Mingograms displaying three signals: -speech wave signal -duplex oscillogram -log of average speech power * Spectro-grams	* Segment durations (of vowel, conso-nants and transi-tion segments in CVC and CCVC words	* Temporal characte-ristics and coordina-tion of consonant *clusters*	*Greater variance in duration values was associated with younger age groups. *Two age groups could roughly be defined by the durations of fricative and resonants: five and seven-year-olds formed one group and nine, eleven-year-olds and adults the other group. *Inspection of the voiceless portion of [l] or [w] showed that the duration of this portion relative to the following voiced [l] or [w] was approximately the same for all age groups. A particular difficulty which may be associated with articulation of [s] in clusters was not reflected in duration (which contrasts with findings of Hawkins,1973). *A proposed sequence of acquisition of clusters was hypothesized. In the adult a fairly rigid timing-dominant system controls duration of speech segments. For the child the time allowed in the adult model is not sufficient for completion of all gestures. To comply with the adult temporal model, the child first omits certain features, eventually learns to establish his own temporal system which allows enough time to complete all the necessary segments. The observation that five and seven-year-olds can be roughly separated from the older age groups on the basis of absolute duration of all consonants measured, is further evidence that the timing program used by children, up to at least seven years, is different from that of adults.

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TABLE 2.6 (-CONTINUED): SUMMARY OF STUDIES ON COARTICULATION AND COORDINATION IN CHILDREN

Researchers	Subjects and Language	Material	Measurement Instruments	Measurements	Aspects of Speech Motor Development	Summary of Major Results / Conclusions
Hawkins (1979)	* Same children as in Hawkins (1979) (called KY1) but recorded one year later (called KY2) * Age range: four to eight years * Five adults	* Word-initial consonant clusters and unclustered consonants (singletons)	* Oscillo-grams	* Selected VOT measurements in singleton and clustered voiceless stops and also in [dr]-clusters. * Duration of clustered and unclustered consonants.	* Temporal coordina-tion of consonant <u>*clusters*</u>	* Clusters with velars [k] and [g] appeared to have been more maturely timed than bilabials and alveolars. (Unexpected since velars generally develop later than bilabial and alveolar stops in younger children). * Durational [s]-modifications were made across all clustered contexts, indicating some evidence for poor control, or at least a different type of control of the timing of [s] in the children's speech compared with the adults. Even though the evidence is not compelling that children have less precise control over their articulation of [s] per se, there is evidence that *clusters involving [s]* may be less maturely timed as whole units than equivalent clusters without an initial [s]. * Some of the data supported the idea of less temporal integration in three-segment clusters in KY1: the figures for [st] vs [spr] and [str] suggested that the overall temporal integration of three-segment clusters had become considerably more mature between KY1 and KY2, while that for two-segment clusters had not changed appreciably. * Generally, an increasing degree of organization was imposed upon the segments of consonant clusters in more mature speakers, and the children's patterns became to represent the adults' more closely with increasing maturity. The degree to which the children's durational modifications corresponded with the adult's appeared to be determined by different factors at different stages of maturity. Maturity of production of particular clusters in younger children (less than five years) was influenced by *homorganicity* and *cluster size* (2 vs 3 segments) and in older children by the *manner* of articulation of the whole *sequence* and *place* of individual segments. * Statements of linking maturity of developmental stages to age must be taken as very approximate and relevant to group data only. Individual children can vary tremendously in the apparent maturity of their articulatory and general timing abilities. * In many cases the children appeared to approximate the adult norm increasingly closely, but there were some clusters whose patterns of modification moved away from the adults' norms: voiceless stops showed this patterns most often.

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In summary, results seem to indicate that although some aspects of coordination and coarticulation may already be like those of adults at certain ages, other aspects may continue to develop long after four years of age. Different factors may also influence these phenomena at different ages. Some forms of coarticulation and/or coordination may be an indication of advanced speech production skills, some may be signs of articulation immaturity, and yet others may be neither because they simply cannot be avoided (Repp,1986). It may thus not be wise to draw conclusions about a general process called coarticulation from the study of a single effect.

Currently we do not possess any conclusive details regarding the normal development of coordination and/or coarticulation of speech movements in normal children over four years, which hampers our understanding of problems in these areas in the speech of children with DSD. Assessment batteries of speech motor development also lack procedures to assess coarticulation and/or coordination. Much research in this area is thus needed in order to resolve the different issues, to clarify observations and hypotheses and ultimately to benefit evaluation and treatment of sensorimotor speech control aspects of DSD.

2.5.5. DEVELOPMENT OF NON-SPEECH ORAL MOVEMENTS AND SPEECH DIADOCHOKINESIS

Not much is known about the developmental sequence or characteristics of <u>non-speech</u> <u>oral</u> <u>movements</u> (i.e. other than vegetative movements) in either normal children or those with DSD, since a limited number of studies exist in this area. More normative information is available regarding <u>speech</u> <u>diadochokinesis</u>, although such knowledge is limited to age-related reports of diadadochokinesis repetition rates and not concerned with descriptions of normal and/or abnormal performance on these tasks.

In this section, general developmental information regarding non-speech oral movements (NSOM) and speech diadochokinesis (S-DDK) will be summarized, while the need for more research in this area and more extensive assessment guidelines will be outlined. This information needs to be considered since it was already established in section 2.4.3. of this chapter, that until the exact nature of the relationship between speech and non-speech movements is established, any assessment battery that focus on speech motor development has to include assessment of *non-speech oral movements*. Since non-speech oral movements are also recommended in treatment programs for the improvement of developmental speech disorders (e.g. M.O.R.E. program of Oetter, Richter and Frick,1988), a discussion of basic issues surrounding it is warranted. Further, *speech diadochokinesis* tasks are still widely used in clinical and research assessment batteries and existing normative information thus have to be expanded.

2.5.5.1. Non-speech oral movements

The term non-speech oral movements generally represents a very wide range of oral behavior in the literature, ranging from the traditional tasks included in *oro-facial* and *pharyngeal assessments* to the execution of *isolated* and *sequenced oral-movements*, and *non-speech diadochokinesis* tasks where repetition rates are determined. Generally, 'non-speech oral movements' seem to refer to any movements performed with the speech mechanism that do not have any linguistic or communicative *intent.*

2.5.5.1.1. Oro-facial and pharyngeal examinations

Through the years, evaluations of non-speech movements in children were usually restricted to oro-facial and pharyngeal examinations, which aimed to observe *structural features* and *functional aspects* of the speech mechanism in all the speech subsystems i.e. articulation, phonation, respiration and resonance. Such examinations are important to perform in children with DSD, since it gives an indication of structural, functional and neurological status of the system. With these examinations, problems such as structural abnormalities, assymetry in size or shape, abnormal color, fasciculations, tremors and tics can be identified. In addition, problems with involuntary movements, muscle tone, force, range rate and range of movements, which can indicate paralysis/paresis and may also directly interfere with sensorimotor speech control (Van der Merwe,1997) can be determined. Kent (1997:27-28) described the goal of structural examination as follows: "Structure refers to anatomy, but anatomy in a living person is not inert. In many respects anatomy is a performance anatomy -that is- a set of structural features and relations that permit functions (actions) and are in turn influenced by these functions. It is therefore helpful to conceptualize a structural examination as a set of "snapshots" of a dynamic system. Each snapshot represents one configuration or function of that system.". In a study of normal speech motor development, subjects will thus have to pass a very strict structural and functional assessment of the oro-pharyngeal structures in the subject selection phase of the study. This is necessary in order to establish that the selected subjects are indeed 'normal' in terms of anatomical and physiological aspects underlying speech production.

It can be emphasized that only a few of the non-speech tasks generally used to assess the phonatory and velopharyngeal systems are truly ***non-speech*** in nature, since most measures used to evaluate the function of these systems for example, require the use of speech (Robin, Solomon, Moon & Folkins,1997).Vowel and single consonant productions are thus also sometimes included under the heading of non-speech assessment, since they do not have any linguistic or communicative intent and are not as multi-system demanding as the production of words and longer units of speech (Robin et al.,1997). However, these tasks do not allow for a clear a distinction between speech subsystems and their compensations among structures.

2.5.5.1.2. Non-speech oral movement tasks

Tasks such as tongue protrusion, puckering lips, touching the nose with the tongue tip to blowing, and moving the tongue from corner to corner of the mouth are also usually included in non-speech oral movement assessments. The purpose of these tasks is to assess the speed, symmetry, distance, and accuracy of movements of the tongue, jaw and lips (Robin et al.,1997), and also to indicate the possible presence of oral apraxia (Love,1992; Crary,1993.). Simple non-

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verbal oral movements are usually examined in isolation (e.g. a single protrusion of the tongue), in a repetition sequence (e.g. several tongue protrusions in a row) or in combination sequences (e.g. sequence of tongue protrusion, lip retraction and jaw opening). As with the relationship between non-speech vegetative tasks such as swallow, chew, and drinking to speech in children, different opinions also exist regarding the clinical usefulness of non-speech assessments in clinical settings and research studies in *adult* populations (Robin et al.,1997). Since the arguments central to this issue are also relevant to the assessment of DSD and research on *normal* sensorimotor speech development, it will be briefly reviewed.

The idea of using non-speech tasks in research regarding sensorimotor speech control has been challenged recently (e.g.Weismer & Liss,1991).Weismer (in Folkins, Moon, Luschei, Robin, Tye-Murray & Moll,1995) has pointed out that many motor tasks involve task-specific control strategies and therefore, one can not generalize from one task to another. He argued that it is inappropriate to use non-speech tasks as a window into speech motor control processes and their disorders.

By contrast, other speech researchers and clinicians have argued that there are good reasons to perform non-speech tasks both clinically and in a research setting (Folkins et al.,1995; Kent,1997; Robin et al.,1997). Their position is that "...nonspeech tasks can provide useful information about the functioning of the motor system that is unique and aids in understanding a person's ability to communicate using the speech production system. Specifically, we believe the combined use of non-speech and speech tasks are beneficial if one's goal is to determine the integrity of the speech motor system." (Robin et al.,1997:49). Robin et al. (1997) argued that such an integrated approach will help to "...separate the contributions to the speech disorder arising from the motor system from contributions to the speech disorder arising from the linguistic system." (Robin et al.,1997:50). Kent (1997) also argued that non-speech tasks offer important opportunities to observe functional characteristics relevant to speech and other oral motor behaviors. Other particular advantages these tasks offer is "...observation of isolated muscle systems performing a specified action

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that is free of phonetic restrictions." (Kent,1997:29). It can also be used to test the strength or endurance of a given motor system. Impairments can indicate dysarthria (which may be evident as slow, inaccurate or incomplete movements), oral non-speech apraxia (Kent,1997) or other sensorimotor control problems (Van der Merwe,1997).

In addition, since speech production involves the interaction and coordination of all speech production sub-systems (such as respiratory, phonatory, velar and articulatory systems) "...in an integrated manner, one cannot assess the relative contribution of a given speech production subsystem to the disorder without using non-speech tasks." (Robin et al.,1997:51). In that sense, non-speech tasks allow the clinician to assess individual structures in order to determine if there is a primary motor involvement of that structure. Non-speech tasks that "...utilize more than one structure can examine the coordination and interaction of multiple structures under controlled conditions, allowing for unambiguous interpretation of motor involvement and compensations." (Robin et al.,1997:51).

Unfortunately not much normative data are available regarding how normal *children* perform on non-speech tasks elicited in traditional assessments of children with DSD. In order to obtain information regarding normal children's performance, one is limited to studies that used normal control groups but which focused on studying pathological subjects, such as children with suspected DAS. However, such studies generally do not report extensively on the nature of the normal subjects' performance. It is true that normal children are not expected to show problems with the basic voluntary execution of non-speech movements (such as those problems found in cases of oral apraxia for example). Yet, in the absence of relevant normative data it can also *not* be assumed that normal children's performance on isolated and especially more complex, sequenced non-speech oral movements will be *completely adult-like* between four and seven years. Data throughout this chapter have shown that many aspects of normal children's speech motor control acquisition continue to develop into puberty and the same may be true of some aspects of non-speech movement execution. Clinically it is important to determine how normal children execute these tasks in order to have a baseline of comparison for children with suspected DSD who may show subtle problems in this area, and also to determine how speech and non-speech performance in children are related (if at all).

Robbins and Klee (1987) developed what they titled an "Oral and Speech Motor Control Protocol" for children, which provided some pioneer normative data on speech and non-speech aspects of physically normal children from 2;6 years to 6;6 years. The protocol covered evaluation of the structure and functioning of the vocal tract, from the lips to the oro-pharyngeal complex and included oral motor (non-speech) and speech tasks (monosyllabic and polisyllabic repetition rates and maximum phonation time). Protocols such as this one, which were developed and tested with children are very important, since the administering of adult-based oral-motor examinations with children would provide limited information, or might lead to misleading or even incorrect information, given that adult tests were intended to be used in the assessment of *mature* speech motor systems (Robbins & Klee,1987). "Inaccurate performance on a test item, which may reflect a deficit in the adult, could represent age-appropriate performance in the child." (Robbins & Klee,1987:271). It follows that the limited amount of normative data and guidelines for assessing oral and speech motor functioning in children below age seven complicates differential diagnosis of DSD.

Further, existing studies judged behavior or performance on very simple items and did not attempt to provide a framework for describing normal behavior, but only used simple rating scales or a mere pass/fail system to judge performance (e.g. Yoss & Darley,1974). Robbins and Klee (1987) for example, implemented a simple three-point rating scale i.e. 2=adult function, 1=emerging skill (e.g. an approximation of target but lacking adult precision) and 0=absent function (e.g. no approximation of the target behavior) to judge their subjects' performance on functional tasks (e.g. lip rounding, pitch variation, tongue mobility). Their subjects obtained total functional scores (TFS) ranging from 78 to 111 (for 2;6 to 3;11 year olds) and 104 to 112 (for 4;0 to 6;11 year olds), indicating that some normal subjects indeed have not reached adult performance precision on oral-motor speech and non-speech movements. The TFS increased by an average of ten points between ages 2;6 and 3;11 and by only four points from that point

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onward. The Robbins and Klee Protocol (1987) however, did not include *sequenced* oral speech movements or coordinated non-speech movements, or *descriptions* of how normal children's performance deviated from the adult norms (e.g. whether associated movements occurred or what imprecision of movements entailed), which limits its application value to the assessment of DSD. It is unlikely for example, that subtle cases of oral apraxia may be identified by the tasks used in the Robbins and Klee protocol, since clinicians like Hall et al. (1993) and Crary (1993) have stressed that single facial postures or movements alone might be too simple and thus might not be sufficient to identify potential oral apraxias. They have both recommended that the speech system needs to be stressed with tasks like sequenced volitional oral movements, diadochokinetic tasks (repeated non-speech movements) or repeated trials. Hall et al. (1993) have also emphasized the need for *description* of behaviors demonstrated during non-speech tasks. Presently however, existing frameworks and/or rating scales of description are extremely limited and simple.

In another study, Ansel, Windsor and Stark (1992) evaluated volitional oral movements in subjects aged six to nine years, since "...children younger than 6 years were found in preliminary work to have difficulty in following instructions to imitate the oral gestures for them...... they probably require a different approach to the assessment of oral movements than was adopted in the present study." (Ansel et al.,1992:4). They scored attempts in terms of three categories i.e. *accuracy, coordination* and *overflow*, but judgements were only made *dichotomously*, with a '0' assigned to inaccurate, uncoordinated production or presence of overflow, or a '1' to accurate, coordinated production or no overflow. They found that their subjects did not show marked changes with age in their error responses, suggesting that by six years of age, they have reached a ceiling level of performance, for at least the easier items in the procedure. In a pilot attempt at assessing younger children, Ansel et al. (1992) found that children aged three to six years had difficulty in sequencing gestures and recommended that if combinatory sequences are included in tests of non-speech volitional movements, they should compromise two items only, at least for four

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to five-year-old children. Ansel et al. (1992:11) concluded that it is "...not a simple matter to assess oral volitional movements in children.".

In the light of the unsolved debate in adult research regarding the *usefulness* of including non-speech tasks in assessment batteries, and due to the *scarcity* of detailed research data for children on the subject, batteries evaluating sensorimotor development in normal children and/or children with DSD, have to include some assessment of non-speech aspects. Expansion of test batteries to include more complex non-speech movement sequences and more comprehensive rating guidelines is also needed.

Financial and practical constraints may limit researchers to fairly simple assessment of non-speech tasks (such as rating the child's execution of isolated or sequenced non-speech oral movements in terms of different categories on a rating scales), in contrast with some of the newer aspects and methods of assessment that include measurements of maximal performance, articulatory strength and fatigability, respiratory tests of speech breathing, lung volume, or air flow, assessing phonation by phonetograms (voice range profile), or testing control of static position and isometric force in non-speech tasks. Motivation for the use of some of these new tasks e.g. visuomotor tracking is that these tasks better reflect some of the motor demands placed on the articulators. At this stage some of these newer non-speech tasks appear to be promising as clinical tools, but further research will determine how much clinical utility it will ultimately have (Robin et al.1997). Until then, assessment procedures developed for non-speech movements have to be practical and affordable in order to optimize their clinical usage.

2.5.5.2. <u>Speech diadochokinesis</u>

Speech diadochokinesis (S-DDK) testing is commonly included in clinical assessments of DSD and sometimes taken as the only indication of speech motor control aspects such as timing, coordination and sequencing. Oral diadochokinesis of speech movements can be said to be a reflection of the

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maximum speed with which the reciprocating articulatory gestures (for example velar opening and closing) can be produced during speech (Lundeen,1950). Laryngeal diadochokinesis tasks, the rapid and repetitive production of glottal plosives may for example, serve as an index of neural integrity of the phonatory system (Verdolini,1994). Since diadochokinesis tasks can be considered to provide some insight into the adequacy of the patient's neuromotor maturation and integrity, it has to be included in a test battery of sensorimotor speech control.

Through the years basic age-related data regarding diadochokinetic repetition rates were determined for a limited number of material (e.g. Fletcher,1972; Ludwig,1983; Robbins & Klee,1987; Irwin & Becklund,1953; Kent,1997). However, no single standardized procedure for eliciting diadochokinesis performance or for measuring the repetition rate exists (Baken,1987). In addition, very limited assessment guidelines in terms of how to rate diadochokinesis performance other than in terms of rate of execution exist, which limits the application value of these tasks. Expansion of age norms in the age range four to seven years is needed, both in terms of repetition rates in different languages, and for different material (i.e. reflecting different types of S-DDK).

2.6. THE APPLICATION VALUE OF KNOWLEDGE REGARDING SPEECH AS SENSORIMOTOR SKILL AND ITS DEVELOPMENT FOR RESEARCH

From the preceding overview of speech as sensorimotor skill and its development, certain implications for research can be deducted and used in the formulation of aims for this study. Firstly, it was established that speech production can be regarded as a *fine-sensorimotor skill*, with certain *characteristics* basic to all motor skills, but that in addition, it also possesses certain unique *variant* and *invariant* temporal and spatial aspects central to its sensorimotor control. Speech motor development research should thus focus on

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the developmental *nature* of these characteristics and/or skills, when formulating research aims.

Further, it was determined that characteristics can be optimally viewed within the *process* of speech production and that a *theory* of the speech production process that separates *linguistic* (non-motor) and *sensorimotor control processes* of speech production clearly, will be suitable to use as a theoretical foundation. As was established in Chapters One and Two, such a division between linguistic and sensorimotor phases of the speech production process is needed in order to ultimately explain suspected sensorimotor control components of some cases of developmental speech disorders more adequately. The *diverse nature* of existing studies of sensorimotor control development, the confusing and interchangeable usage of *terminology,* and the fact that most interpretations of findings are still mere *hypotheses,* all are factors that call for the implementation of some kind of organizational framework of the speech production process. Such a framework can be used to define terminology, identify and formulate research aims and to help with the integrating and interpretation of findings. The unique, *four-level model* of mature speech production of Van der Merwe (1997) was identified as a model with application value in research of sensorimotor speech control development.

Further, it was established that speech motor development takes place against a constantly *changing* neurobiological and neurophysiological environment, all of which may affect sensorimotor speech control characteristics in children to some extent. Broad developmental *phases* of speech motor development have been identified from birth to two years of age, but it was determined that possible phases between two years and puberty have *not* yet been distinguished. Such information is needed, since it is evident from the review of research in this chapter that normal sensorimotor speech control continues to develop into *puberty*, a fact that has both research and clinical implications. It was also deducted from the information in this chapter that existing research of speech motor development after two years of age is *scarce* and *limited,* very *diverse* in nature, and clouded by different *unresolved issues* and *questions*. The lack of

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specific *normative developmental information* for especially children between 4;0 and 7;0 years, an age range when many children are referred for persistent DSD, also became apparent. This is an unfortunate situation, which affects clinical assessment and treatment of DSD negatively. In the Afrikaans language, even *less* normative information is available regarding speech motor development in this age range, which hampers service delivery to this population even further.

Based on the information discussed in this chapter, the following aspects of speech motor development in normal, Afrikaans-speaking children were identified as focus of this study. A specific parameter or aspect was selected based on factors such as its current *inclusion* in speech motor developmental test batteries, a *limited* existing amount of normative information regarding its development, specific *issues* surrounding its development, its potential *contribution* to the overall understanding of the process of sensorimotor speech control, its practical measurement or assessment *potential,* and its potential *clinical applicability* in terms of inclusion in a battery of speech motor assessment used with DSD. Together, these factors represent a wide range of children's sensorimotor speech skills. Additional theoretical motivation for the inclusion of the specific parameters will be provided in Table 3.1. (Chapter 3). The aspects selected for inclusion in the test battery of this study are briefly defined in Table 2.7.

TABLE 2.7: ASPECTS SELECTED FOR INCLUSION IN THIS STUDY

PARAMETER OR ASPECT	DEFINITION AND/OR SKILL
Isolated and sequenced non-speech oral movements (NSOM)	Non-speech oral movements refer to any movements performed with the speech mechanism, which do not have any linguistic or communicative intent. Such movements assess the ability to execute isolated, as well as two and three-sequenced non-speech oral movements voluntarily.
Non-speech diadochokinesis (NSO-DDK)	This involves repetitive non-speech movements of the articulators and assesses the ability to execute repetitive, non-speech oral movements.
Speech Diadochokinesis (S-DDK)	This involves repetitive verbal productions of one, two, and three-syllable sequences.
Cluster production	This refers to the production of clusters in isolation (e.g. [bl-]). It reflects the ability to plan and combine consecutive speech motor goals without linguistic influences.

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TABLE 2.7 (-CONTINUED): ASPECTS SELECTED FOR INCLUSION IN THIS STUDY

PARAMETER OR ASPECT	DEFINITION AND/OR SKILL
Word syllable structure in spontaneous speech	This refers to the combination or arrangement of consonants and vowels in spontaneously spoken words (e.g. the Afrikaans word [kləp] has a word syllable structure of CCVC).
First-vowel duration (FVD)	This refers to the length or duration (in milliseconds) of the first vowel in a word.
Variability of first vowel duration	This refers to the extent to which first-vowel duration (in milliseconds) varies from production to production (i.e. token-to-token).
Voice onset time (VOT)	It can be defined as the time interval (in milliseconds) between the burst release of a stop consonant and the onset of voicing (Lisker & Abramson,1964).
First-syllable duration (FSD) in words of increasing length	This refers to the length or duration (in milliseconds) of the first syllable in words of increasing length (e.g. [blɔm], [blɔmə], [blɔmbakə]).

Assessment of this variety of aspects of speech motor development in normal children will provide more extensive normative information than presently available, which will ultimately enhance comprehensive assessment (differential diagnosis) and treatment of developmental speech disorders. This information may also contribute to a better understanding of relevant issues surrounding normal sensorimotor speech control development and the process of adult sensorimotor speech control in general.

2.7. CONCLUSION

In this chapter a theoretical basis for the study of speech motor development was established, by reference to components of motor systems (such as motoneurons, types of movements and their neural control, motor goals, motor programs and motor plans) and adult sensorimotor speech control (such as the characteristics of speech as a fine sensorimotor motor skill, and the process of sensorimotor speech control as hypothesized by Van der Merwe,1997). In addition, information about the basic variant and invariant aspects of speech production and sources of variance in spatial and temporal aspects of speech movements was provided.

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Following these theoretical underpinnings of the study, the rest of the chapter consisted of an overview of existing knowledge about sensorimotor speech development and factors influencing it. It was emphasized that speech motor development takes place against a background of change. Possible stages of motor and vocal development in the age period infancy to two years were described with reference to some neurobiological and physiological developmental aspects. Controversial issues concerning the relationship between speech and non-speech movements were also discussed.

Speech motor development after two years of age was then summarized, based on an assortment of diverse studies that have investigated temporal and spatial parameters/aspects of sensorimotor speech control, such as voice onset time (VOT), speaking rate, word and segmental duration, variability in children's speech, coordination and/or coarticulation, as well as the development and assessment of non-speech movements. Finally, the implications of all this information for the study of speech motor development were briefly discussed while aspects of sensorimotor speech control selected for inclusion in this study were defined.

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CHAPTER 3

RESEARCH METHOD

3.1. INTRODUCTION

It is evident from the previous two chapters that sensorimotor speech control development is a complex process, influenced by many different factors. It was illustrated that the currently existing, normative database regarding normal speech motor development is limited and diverse in nature, and does not provide adequate information against which the performance of children with possible developmental speech disorders can be clinically compared to. Expanded normative information is especially needed in the clinically important age range of four to seven years. It was determined that in order to expand this information basis, research methods have to be carefully designed in order to address *sensorimotor control* aspects of the speech production process clearly. It is essential that, although speech is essentially related to language aspects (by being the externalized expression of language), a clear distinction should be maintained between linguistic (non-motor) and sensorimotor processes of speech production in research regarding speech motor development. The method of this study was compiled with these clinical and theoretical needs in mind and designed to focus on a variety of developmental aspects of sensorimotor speech control. There was aimed to optimize clinical and practical applicability of the assessment battery and assessment guidelines.

This chapter will present the aims for this study, together with theoretical motivations for their inclusion, definition of terminology, as well as the research design. The subject selection criteria and the procedure for subject selection will then be outlined, together with details of material compilation and choice of measurement instruments. Finally the data collection, recording, assessment and data analysis procedures will be described.

3.2. AIMS OF THE STUDY

Aims were selected based on the characteristics of speech as a unique, yet essentially fine-sensorimotor skill, and sensorimotor control processes underlying its production as hypothesized by Van der Merwe (1997). Aims were also considered in terms of practical aspects such as ease of measurement and analysis, together with their potential for inclusion as items on an eventual clinical test battery of speech motor development.

3.2.1. MAIN AIM

The main aim of this study was to collect general, normative information regarding certain sensorimotor speech control abilities in normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years. In order to attain this goal, a test battery with the purpose of assessing certain temporal and spatial aspects of children's sensorimotor speech control was compiled, with reference to a theoretical framework of speech production. The framework of speech production proposed by Van der Merwe (1997) was found to have application value in this respect, since it delineates possible phases of the speech production process, distinguishes between linguistic and sensorimotor processes of speech production, and identifies possible temporal and spatial parameters involved in the sensorimotor control of speech movements.

3.2.2. SUB-AIMS

In order to examine different aspects of speech motor development, the following sub-aims were selected. Theoretical motivation for their selection and definitions of terminology related to these sub-aims are provided in Table 3.1.

3.2.2.1. Sub-aim one

To investigate the ability of normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, to plan and execute *isolated (I-OM)*, *two-sequence (2S-OM)*,

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and *three-sequence (3S-OM) voluntary, non-speech oral movements (NSOM)* on request, by the application of a comprehensive *rating scale* designed for assessing performance on these tasks.

3.2.2.2. Sub-aim two

To investigate the ability of normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, to plan and execute *repetitive, non-speech movements* of the tongue, lips and jaw in *non-speech oral diadochokinesis (NSO-DDK)*, imitative tasks, by the application of a comprehensive *rating scale* designed for assessing performance on these tasks.

3.2.2.3. Sub-aim three

To investigate the ability of normal, Afrikaans-speaking children aged 4;0 to 7;0 years to produce repetitive speech movements in *speech diadochokinesis (S-DDK)* tasks, involving tongue, lip, velar and glottal movements as elicited in single, two-place and three-place imitative articulation tasks, by firstly calculating *diadochokinetic rate (DDR)* on these tasks and secondly, by applying a comprehensive *rating scale* designed for assessing performance on these tasks.

3.2.2.4. Sub-aim four

To investigate the ability of normal, Afrikaans-speaking children aged 4;0 to 7;0 years to *recall, plan, organize* and *combine motor goals consecutively* during imitative productions of two (CC), and three-consonant (CCC) initial and final clusters.

3.2.2.5. Sub-aim five

To investigate the ability of normal, Afrikaans-speaking children aged 4;0 to 7;0 years to *recall, plan, organize* and *combine* a variety of *motor goals consecutively for* different *word syllable structures, as* manifested in *spontaneous speech* production.

3.2.2.6. Sub-aim six

To determine acoustically the following aspects of segmental duration in normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, in repeated utterances of the same word:

(a) To obtain *normative* indications of the length of *first-vowel duration (FVD)* in this age range and to determine if any differences exist in the vowel durations of the age groups (i.e. four, five, and six-year-olds).

(b) To investigate the nature of *variability* in first-vowel duration in this age range and to determine if any differences in vowel duration variability exist between the age groups (i.e. four, five, and six-year-olds).

3.2.2.7. Sub-Aim seven

To obtain normative, acoustic indications of the nature of *voice onset time (VOT)-values* of voiced and voiceless Afrikaans stops in normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, as measured in repeated utterances of the same word.

3.2.2.8. Sub-aim eight

To investigate acoustically if normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years make any adaptations in first-syllable duration *(FSD)* in imitated words of *increasing length* and if so, what the nature of these adaptations is.

TABLE 3.1: SUB-AIMS AND RATIONALES

SUB-AIM	RATIONALE
SUB-AIM ONE: To determine the ability of normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, to plan and execute *isolated (I-OM), two-sequence (2S-OM)*, and *three-sequence (3S-OM) voluntary, non-speech oral movements (NSOM)* on request, by the application of a comprehensive rating scale designed for assessing performance on these tasks.	-Limited data is available regarding the performance of normal children of all languages in this area, resulting in limited knowledge about the *range* of *normal, acceptable behaviors* in the age range 4;0 to 7;0 years. -*Limited assessment guidelines* hinder the identification of subtle problems with non-speech oral movements and/or sequences. Current assessment is merely based on a score/pass system with limited *description* of normal and/or abnormal performance criteria. -As no final conclusion has yet been drawn about the *nature* of the relationship between non-speech oral movements and speech production, a test battery of sensorimotor speech control development need to include some measure of isolated and sequential non-speech oral movements. Robin et. al (1997:49) stated that "...the combined use of non-speech and speech tasks are beneficial if one's goal is to determine the integrity of the speech motor system.". -The fact that non-speech movements also continue to be used clinically in certain therapy programs aimed at improving sensorimotor speech control in children, further emphasizes the need for data regarding normal children's performance on these tasks. Normal data can serve as reference to determine problems and/or to measure improvement in cases of developmental speech disorders (DSD). -In a clinical setting the purpose of these tasks will be to assess *speed, symmetry, distance* and *accuracy* of tongue, jaw and lip movements (Robin et al.,1997) and/or to indicate the presence of *developmental oral apraxia* (Love,1992; Crary1993). -Developmental oral apraxia can be defined as an "..inability to perform voluntarily movements of the muscles of the pharynx, tongue, cheeks and lips, although automatic movements of these muscles may be preserved. In other words, it's an apraxia of non-speech acts." (Love,1992:10).
SUB-AIM TWO: To determine the ability of normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, to plan and execute *repetitive, non-speech movements* of the tongue, lips and jaw in *non-speech, oral diadochokinesis (NSO-DDK)*, imitative tasks, by the application of a comprehensive *rating scale* designed for assessing performance on these tasks.	- Limited data are available regarding the performance of normal children of all languages in this area, resulting in limited knowledge about the *range* of *normal, acceptable behaviors* in children aged 4;0 to 7;0 years -*Limited assessment guidelines* hinder the identification of subtle problems with non-speech diadochokinetic movements. Current assessment is merely based on a score/pass system or determining maximum speed of performance, with limited *description* of normal and/or abnormal performance. This hampers differential diagnosis and applicability of these tasks. -Some researchers have argued that non-speech oral diadochokinesis tasks may "...represent the simpler motor substrate upon which speech movements were built." (Baken,1987:447), and that it can be indicative of the underlying neural integrity of the system (Robin et al.,1997). Others have argued that the relationship between speech and non-speech oral diadochokinesis tasks is at best weak (Hixon & Hardy in Baken,1987). Since the review of research (see Chapter 2) has indicated that no final conclusion has yet been drawn about the *nature* of the relationship between non-speech oral movements and speech production, a test battery of sensorimotor speech control development has to include some measure of NSO-DDK for the sake of completeness.

TABLE 3.1 (-CONTINUED): SUB-AIMS AND RATIONALES

SUB-AIM	RATIONALE
SUB-AIM THREE: To determine the ability of normal, Afrikaans-speaking children aged 4;0 to 7;0 years to produce repetitive speech movements in *speech diadochokinesis (S-DDK)* tasks, involving tongue, lip, velar and glottal movements as elicited in single, two-place and three-place, imitative articulation tasks, by firstly calculating *diadochokinetic rate (DDR)* on these tasks and secondly, by applying a comprehensive *rating scale* designed for assessing performance on these tasks.	-Jenkins and Elston (1941:13) stated that "The production of articulate speech demands manipulative movements of the jaw, lips, and tongue that are much faster than those demanded by the basic functions of chewing, sucking and swallowing.... A test of diadochokinesis of the articulators is a measurement of the maximum rate at which the reciprocating synapses of the central nervous system may function for speech uses.". -Diadochokinesis can also be defined as the "...ability to perform rapid repetitions of relative simple patterns of oppositional contractions." (Baken,1987:445). The rate of diadochokinesis can also be taken as "...an indication of the speed of change from inhibition to stimulation of antagonistic sets of muscles." (Jenkins & Elston,1941:13). -Speech diadochokinesis can be said to be a reflection of the *maximum rate* with which the reciprocating articulatory gestures (for example velar opening and closing) can be produced during speech (Lundeen,1950). It may provide some insight into neuromotor maturation and sensorimotor speech control aspects such as speed, sequencing and coordination. Lundeen (1950) theorized that different diadochokinetic developmental rates and points of maturation may be evident for various consonants. -Presently some diadockhokinetic rates (DDR's) are mostly available for older children and adults, and only for limited material of mostly the English language. The study of Bernstein (1980) for example, is the only study that could be identified that investigated (S-DDK) to some extent in Afrikaans-speaking children. However, the study only presented data of children between the ages of five and six years, and used three-syllable trains only as material. The lack of normative data affects the evaluation of S-DDK-skills in children with developmental speech and language disorders negatively. Since S-DDK-testing is still widely used in clinical assessments, a need for more comprehensive assessment guidelines exists.
SUB-AIM FOUR: To determine the ability of normal, Afrikaans-speaking children aged 4.0 to 7.0 years to *recall, plan, organize* and *combine motor goals consecutively* during imitative productions of two (CC), and three-consonant (CCC) initial and final clusters.	-This may test the child's ability to firstly *recall* invariant core motor plans with temporal and spatial specifications of speech movements (goals) from the sensorimotor memory (Van der Merwe,1997) for each phoneme in the cluster, on demand. Chappel (1973:362) defined the full repertoire of English phonemes as "....the set of articulatory gestures requisite for producing all the English sounds.", which reflects more or less the same orientation as Van der Merwe (1997). Van der Merwe (1997) hypothesized that the core motor plan/s are attained during speech development and the motor specifications and sensory model (what it feels and sounds like) are stored in the sensorimotor memory. -Secondly, it may test the child's ability to *plan* and *sequentially organize* the consecutive movements (motor goals) necessary to fulfill the spatial and temporal goals for each sound's production (Van der Merwe,1997). Coarticulation potential is also created (Van der Merwe,1997). Motor goals such as lip rounding, jaw depression, glottal closure, or lifting of the tongue tip need to be specified (Van der Merwe,1997).Motor planning is articulator-specific and *interarticulatory-synchronization* also needs to be planned for the production of each phoneme (Van der Merwe,1997).

TABLE 3.1 (-CONTINUED): SUB-AIMS AND RATIONALES

SUB-AIM	RATIONALE
SUB-AIM FOUR: (-continued) *(See previous page)*	-This sub-aim further assesses the more complex ability of *sequencing* and *combining* a *series of movements* (motor goals) for two- (CC-clusters) and three phonemes (CCC-clusters) in succession. The planning of consecutive speech movements for a series of phonemes entails the specification of various co-occurring and successive motor plan sub-routines for different articulators (Van der Merwe,1997). -It is acknowledged in the literature that the acquisition of consonant clusters usually takes place anywhere from about age 3;6 to age 5;6 and that some clusters may even prove to be difficult for some school-aged children (Lowe,1994). It was also found that the timing of sounds within consonant clusters is not yet comparable to adult performance (Gilbert & Purves, 1977; Hawkins, 1979). However, limited data exist in terms of how normal children produce consonant clusters in isolation. Such information can provide valuable normative information for use in clinical assessment of developmental speech disorders.
SUB-AIM FIVE: To determine the ability of normal, Afrikaans-speaking children aged 4;0 to 7;0 years to *recall, plan, combine* and *produce* a variety of *motor goals* consecutively *for* different *word syllable structures, as* manifested in *spontaneous speech* production.	-The term *word syllable structure* refers to the nature of vowel, consonant and diphthong combinations in a word. The nature and complexity of word syllable structures produced by the child in spontaneous speech may give some indication of the child's ability to plan and produce a variety of different motor goals consecutively for speech production. -The planning of consecutive speech movements for a series of phonemes entails the specification of various co-occurring and successive motor plan sub-routines for different articulators (Van der Merwe,1997). -Presently, no data exist to the knowledge of the examiner regarding the nature of word syllable structure in spontaneous utterances of Afrikaans-speaking children aged 4;0 to 7;0 years. The information in this study may thus serve to provide valuable normative information for comparison with children with developmental speech disorders.
SUB-AIM SIX: To investigate acoustically the following aspects of segmental duration in normal *(-continues)*	-The sound systems of all languages consist of a set of discrete phonemes that are invariant units lacking durational values. During the process of speech production, phonemes are act upon by an elaborate set of rules and are converted into phonetic units, which manifest durational values and temporal variability (Smith,1978). Research indicated that *segmental duration* (of both vowels and consonants), has to be adjusted to the sound environment in which it occurs, and that this environment is *language-specific* (Smith,1978; DiSimoni,1974:1;b;c; Calvert,1980; Walsh,1984). Limited data are currently available concerning durational aspects in normal, Afrikaans-speaking children's speech.

TABLE 3.1 (-CONTINUED): SUB-AIMS AND RATIONALES

SUB-AIM	RATIONALE
SUB-AIM SIX: *(-continued)* .....Afrikaans-speaking children in the age range 4;0 to 7;0 years, in repeated utterances of the same word: (a) To obtain *normative, acoustic* indications of the length of *first-vowel duration (FVD)* in this age range and to determine if any differences exist in the vowel durations of the different age groups (four, five and six-year-olds) (b) To investigate the nature of *variability* in first-vowel duration in this age range and to determine if any differences in vowel duration variability exist between the age groups (four, five and six-year-olds)	-Segmental duration (e.g. vowel duration) may yield information about the *nature* of temporal speech planning for first vowel duration (FVD) in Afrikaans and sensorimotor control of speech timing aspects in general. Expanded information is also currently needed regarding factors that may influence vowel duration in different contexts. -Variability and duration may reflect different but important aspects of sensorimotor speech control development in general (Smith,1992). -Consistent timing and sequencing of speech movements are critical components of speech movement coordination , as it facilitates the achievement of the speech movement goal (Gracco & Abbs,1988). In order to reach the critical acoustic configuration (Lindblom et al.,1979), spatial and temporal adaptations of speech movements to the context have to be kept within certain limits of equivalence. Variability of speech movements can thus only occur to a certain extent. "The spatial and temporal differences between certain sounds are in many cases minimal, and if these boundaries are violated, the sound will be perceived as being distorted or even substituted by another sound." (Van der Merwe,1997:12). -Although it is generally accepted that children show more consistent speech movements with increased age, it has been suggested that several factors may affect performance variability e.g. individual trends in performance, different phonetic contexts and the type of sensorimotor parameter, articulator or subsystem measured (*See review in Chapter 2*). Since the influences of these factors are only beginning to be explored and not yet well understood at all, extensive research is still needed. -In addition, the reason for the occurrence of variability in children's speech has not been established. Information from this study will thus contribute to the general database concerning variability in children's speech movements.
SUB-AIM SEVEN: To obtain normative, acoustic indications of the nature of *voice onset time (VOT)-values* of voiced and voiceless Afrikaans stops in normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, as measured in repeated utterances of the same word.	-VOT can be defined as the time interval between the articulatory release of a stop consonant and the onset of vocal fold vibrations (Kent & Read,1992). -VOT is a temporal characteristic of stop consonants that reflects the complex timing of glottal articulation relative to supraglottal articulation (interarticulator synchronization) (Tyler & Watterson, 1991). -Interarticulator synchronization is an important part of speech planning, as it has to be planned for each phoneme in an utterance (Van der Merwe,1997). - To the knowledge of the examiner no data exist regarding the nature of VOT and vowel duration in Afrikaans-speaking children aged 4;0 to 7;0 years. This lack of normative data limits deductions about these aspects in studies of speech motor development in children with developmental speech disorders.

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YUNIBESITHI YA PRETORIA

TABLE 3.1 (-CONTINUED): SUB-AIMS AND RATIONALES

SUB-AIM	RATIONALE
SUB-AIM EIGHT: To investigate acoustically if normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years make any adaptations in first-syllable duration (FSD) in imitated words of *increasing length* and if so, what the nature of these adaptations are.	-No data exist, to the knowledge of the examiner regarding the effect of increased word length on segmental duration (first CV syllable) in the speech of Afrikaans children aged 4;0 to 7;0 years. Such information may throw some light on normal children's sensorimotor speech control abilities. -Van der Merwe (1997) theorized that during the speech motor planning phase of speech production, the core motor plan of the phoneme has to be adapted to the context of the planned unit. Less complex, short utterances probably put less demand on speech motor planning than longer complex utterances. In a longer complex utterance increased coarticulation potential is created and higher demands are placed on the speech planning system in terms of the planning of consecutive movements, such as the sequential organization of movements for each phoneme and inter-articulator synchronization (Van der Merwe,1997).

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

3.3. RESEARCH DESIGN

Leedy (1993:139) stated that "The nature of the data and the problem for research dictate the research methodology. If the data is verbal the methodology is qualitative, if it is numerical the methodology is quantitative.". In this study both types of data were obtained due to the nature of the assessment battery. Qualitative and quantitative data are compatible and may co-exist in a single study, which may be called "methodological triangulation" (Duffy in Leedy,1993). Methodological triangulation firstly serves to enhance results (Kathleen, Knafl, Pettingil, Bevis & Kirchoff in Leedy,1993), secondly, may provide a holistic view of what is being studied and thirdly, may enhance an unbiased, objective view of results (Stainback & Stainback in Leedy,1993).

A *multi-subject case-study design* was used. Subjects were individually exposed to the test battery and their performance examined and described both qualitatively and quantitatively.

3.4. SUBJECTS

Normal children's speech motor development skills were the focus of this study. Selected subjects had to adhere to the following criteria in order to assure that they were representative of the target group and indeed 'normal' in terms of several developmental aspects.

3.4.1. CRITERIA FOR SUBJECT SELECTION

The following criteria were used for subject selection:

3.4.1.1. Age

Children falling in the age range 4;0 years (i.e. 4 years and 0 months old) to 7;0 years (i.e. 7 years and 0 months) were used in the study. Firstly, by age four, children are usually able to give more *satisfactory cooperation* in a formal test

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

environment than younger subjects, which enhances the reliability of results. Secondly, limited and diverse normative information regarding speech motor development exists for children in this age range, with the majority of information focusing on *linguistic* aspects such as phonological development. This is unfortunate when considering that "...most children's communicative difficulties emerge during the pre-school years." (Dodd,1996:63), resulting in a *high number* of children being referred for clinical assessment in this age range. The data obtained in the study are thus of *clinical assessment value* since it provide guidelines of the *range* of speech motor behavior that can be considered acceptable (i.e. normal) for children in this age range, in terms of the assessment categories.

Further, the data provide information regarding what normal sensorimotor speech control development consists of *after four* years of age. Although research has indicated that the period after four years of age (up to even 14 years) may be a period of further gradual acquisition and refinement of several aspects of sensorimotor control such as timing, coarticulation and speech gesture coordination (DiSimoni,1974:a,b; Smith,1978; Netsell,1986; Smith & McLean-Muse,1986; Sereno et al.,1987; Smith & Kenney,1998), details about the development of these aspects are not yet known.

In addition, the assessment of normal children between 4;0 and 7;0 years provide some indication of the effect of *maturation* in sensorimotor speech control development, since a three-year period was covered. However, no children older than 7.0 years were selected, in an attempt to limit the influence of maturational factors to some extent.

3.4.1.2. Gender

As some researchers (e.g. Walker et al.,1992) have found at least some indication of gender-related trends in speech developmental data, an equal number of boys and girls was selected, in order to control for the possible influence of gender. Gender numbers were also balanced in order to increase the representative nature of the sample.

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

3.4.1.3. Intelligence and concentration

No indication of cognitive impairment as judged by both the referring nursery school teacher and the examiner had to be present, as to exclude the possibility of low intelligence influencing results. As a control measure, each subject had to have reached general developmental milestones and basic self-help skills within normal limits, as judged by the examiner during the pre-interview with the parents. Subjects had to display average-to-above-average concentration skills and had to possess the ability to follow instructions well, as judged by both the referring teacher and the examiner.

3.4.1.4. Language and speech skills

Normal, Afrikaans-speaking children were used, since limited normative data of their sensorimotor speech control development exist. Subjects had to display age-appropriate receptive and expressive language and speech skills in the Afrikaans language, as judged by the referring teacher. As control measure, the examiner assessed *expressive language skills* by means of information obtained during the parent interview and a screening session with the child. As control measure for *receptive language* skills, a subject had to score within age limits on an Afrikaans receptive vocabulary test called the "Afrikaanse Reseptiewe Woordeskattoets" (ARW:Buitendach,1994), administered by the examiner.

Only children that were able to produce all the consonants, vowels and diphthongs of the Afrikaans language were selected, as to prevent a possible articulation disorder to influence results. Subjects also had to have no remaining phonological processes in their speech, as to control for the possible influence of a developmental phonological disorder. In addition, subjects should not have had any history of speech and/or language therapy.

3.4.1.5. Hearing and middle-ear status

Subjects had to have no history of sensorineural or conductive hearing loss, since hearing loss may influence speech production. Further, subjects should not have

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

suffered six or more episodes of recurrent otitis media with effusion in their lives. Many studies have shown that individuals with a history of fluctuating conductive hearing loss during the early years of life, are at risk for language, speech, learning and auditory processing problems (Katz & Wilde, 1985; Olswang, Rodriguez & Timler,1998). On the day of testing subjects had to pass screening hearing and immittance tests, in order to ensure the absence of any hearing loss or middle-ear infection. Subjects had to obtain hearing levels of 15dB or better at 500Hz, 1000Hz and 2000Hz and Type A tympanograms bilaterally, in order to pass the screening (Northern & Downs,1991).

3.4.1.6. Anatomical aspects

No previous or present anatomical abnormalities of the body or speech mechanism as caused by diagnosed syndromes or cleft lip and/or palate had to be present, since such abnormalities can cause speech sound distortions. Teeth had to be intact, since missing teeth can influence articulation.

3.4.1.7. Neuromotor abilities

Subjects had to be free of any paresis, paralysis, abnormal reflexes and involuntary movements of the body and oral musculature, in order to exclude dysarthric populations. No history of feeding problems (e.g. swallowing, sucking or chewing problems), immobility of oral musculature, or drooling should ever have been present. As control measure, subjects had to pass a screening oro-facial and oro-pharyngeal examination performed by the examiner (based on a procedure outlined by Louw & Van der Merwe,1981).

3.4.2. PROCEDURE FOR SUBJECT SELECTION

Nursery school teachers from two nursery schools in the same neighborhood, were asked by letter, to refer children in their class who adhere to all the subject criteria (listed and explained in the letter). The examiner conducted a short interview with each referring teacher in order to confirm that the referred child indeed matched all the criteria.

An evaluation session was then scheduled with the parents and child. First, a parent interview was conducted in order to confirm the child's candidacy for the study from background information provided by the parent/s. Secondly, the examiner then spent ten minutes interacting with the child informally during play, in order to screen for possible speech, language, attention and developmental problems. An oro-facial examination was also conducted. The child then received a screening pure-tone hearing test according to procedures described by Barret (1985) and Margolis and Shanks (1985). In addition, no indication of middle-ear infection had to be present during an immittance screening procedure. Only children that had passed all these pre-assessment procedures were chosen as subjects and the examiner then proceeded to administer the test battery.

3.4.3. SUBJECT DESCRIPTION

Ten subjects *(mean age: 5;2 years)* that matched the criteria in all aspects were selected. Due to the intensive nature of research in the area of sensorimotor speech control development, small subject groups are generally characteristic of such studies. It was not aimed to obtain an equal number of children in each age group, since statistical age-group comparisons were not the main aim of this study. These ten subjects were considered a representative number of subjects, since it would provide information about the expected *normal range* of speech motor skills that may be characteristic of normal speaking children aged 4;0 to 6;7 years. A description of the selected subjects is given in Table 3.2.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

TABLE 3.2: SUBJECT DATA

SUBJECT (S) NUMBER	GENDER	DATE OF BIRTH	CHRONOLOGICAL AGE ON DAY OF TESTING
Subject 1 (S1)	Male	1992-10-27	4 years & 0 months (48 mths)
Subject 2 (S2)	Female	1992-09-14	4 years & 1 month (49mths)
Subject 3 (S3)	Male	1992-01-31	4 years & 8 months (56mths)
Subject 4 (S4)	Female	1991-10-15	5 years & 0 months (60mths)
Subject 5 (S5)	Female	1991-05-28	5 years & 3 months (63mths)
Subject 6 (S6)	Male	1991-06-26	5 years & 4 months (64mths)
Subject 7 (S7)	Male	1991-07-10	5 years & 4 months (64mths)
Subject 8 (S8)	Female	1991-04-02	5 years & 6 months (66mths)
Subject 9 (S9)	Female	1990-02-08	6 years & 1 month (73mths)
Subject 10 (S10)	Male	1990-03-22	6 years & 7 months (79mths)

3.5. MATERIAL AND APPARATUS

The test battery material selected and compiled for each sub-aim of the study will now be discussed and motivated. This will be followed by a description of apparatus used.

3.5.1. COMPILATION OF TEST BATTERY MATERIAL

The test battery was compiled in order to address the sub-aims of the study and allowed for the assessment of a *variety* of aspects of sensorimotor speech control development. As described previously, the aims of the study were also selected to have some clinical application value in terms of the assessment of speech motor development. In addition, it is also planned to use the same test battery in a future study of speech motor development in children with developmental speech disorders. Based on these goals, the test battery was compiled to be relatively *simple*, of *limited length* and relatively *easy* to administer to *children*. Further, material was carefully compiled in order to also ease and assist possible translation to other South African languages.

3.5.1.1. Material compiled for sub-aim one: Non-speech oral movements (NSOM)

Material that elicits isolated non-speech oral movements (I-OM), two-sequence non-speech oral movements (2S-OM), as well as three-sequence non-speech oral movements (3S-OM) was compiled. With regard to all three sections, materials used by Bernstein (1980) and De Kock (1994) were reviewed and some suitable material from the two studies was eventually included, as to allow for some extent of comparison of results.

In the section *isolated non-speech oral movements* (I-OM), material familiar to children, that reflects simple, non-speech oral movements of the cheeks, lips and tongue was chosen. In the section *two-sequence non-speech oral movements* (2S-OM), material assessing movements of a variety of different articulators such as those of the tongue, lips, cheeks and larynx was selected. Two tasks, namely "blow a kiss" and "cough" were performed with accompanying hand gestures. The examiner did not expect this to influence results, since these hand gestures naturally accompany these non-speech oral movements. In addition, the hand gestures were also included since it added an element of "fun" to the test situation, which was thought to have the potential of influencing cooperation positively. In addition, it also reflects the additional dimension of a non-speech oral movement combined with an accompanying body movement. Further, at least one target behavior from section one was included in order to maintain some familiarity.

Material for section three, *three-sequence non-speech oral movements* (3S-OM), was compiled as to include some material from the previous categories for the sake of familiarity, but also to include new non-speech oral movements, as to prevent "motor learning" from interfering with sequencing results. *Test/Recording and Rating Sheets* were also compiled (See Appendix A). The material compiled for this aim is outlined in Table 3.3. Key words central to each target movement were indicated as an aid to memory recall during execution.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

TABLE 3.3: MATERIAL COMPILED FOR SUB-AIM ONE

Target Isolated Oral Movements (1-OM)	Target Two-sequence Oral Movements (2S-OM)	Target Three-sequence Oral Movements (3S-OM)
1.1 "Show me how to blow out a candle". 1.2 "Puff out your cheeks". 1.3 "Show me how you lick an ice cream".	2.1. "Blow a kiss and cough". Key words: *"Kiss, cough"* 2.2. "Pout (pucker) your lips and then touch your left and right lip corners fast with your tongue" (lateralize tongue outside mouth). *Key words: "Lips, tongue"* 2.3. "Puff out your cheeks and then touch your left and right lip corners fast with your tongue (lateralize tongue outside mouth). *Key words: "Cheeks, tongue"*	3.1. "Pout (pucker) your lips, puff out your cheeks and stick out your tongue". *Key words: "Lips, cheeks, tongue"* 3.2. "Blow a kiss, try to touch your nose with your tongue and show me how to blow out a candle". *Key words: "Kiss, nose, candle"*

3.5.1.2. Material compiled for sub-aim two: Non-speech oral diadochokinesis (NSO-DDK)

Selected material from Van der Merwe (1975) was used. The different material compiled for the evaluation of non-speech oral diadochokinesis (NSO-DDK) of the tongue, lips and jaw are depicted in Table 3.4. A *Test/Recording/Rating Sheet* was also compiled (See Appendix B).

TABLE 3.4: MATERIAL COMPILED FOR SUB-AIM TWO

1. **Oral diadochokinesis of side-to-side tongue movements (lateralization outside the mouth):** The child is asked to move the tongue as fast as possible from one lip corner to another outside the mouth, repeatedly, until the examiner tells him/her to stop (time-period of five seconds).
2. **Oral diadochokinesis of in-out tongue movements (stick tongue in and out of mouth):** The child is asked to move the tongue as fast as possible in and out of the mouth, repeatedly, until the examiner tells him/her to stop (time-period of five seconds).
3. **Oral diadochokinesis of pout (pucker)-and-stretch lip movements:** The child is asked to pout (pucker) and stretch the lips as fast as possible, repeatedly, until the examiner tells him/her to stop (time-period of five seconds).
4. **Oral diadochokinesis of jaw opening-and-closing movements:** The child is asked to open and close the mouth as fast as possible, repeatedly, until the examiner tells him/her to stop (time-period of five seconds).

3.5.1.3. **Material compiled for sub-aim three: Speech diadochokinesis (S-DDK)**

The material was compiled as to allow for the evaluation of speech diadochokinesis (S-DDK) in different articulators and in different contexts, based on recommendations by Van der Merwe (1975). Velar (VDDK) and glottal diadochokinesis (GDDK) were only formally evaluated in one context each, namely a CVCV-utterance, in order to limit the length of the test battery. Tongue and lip diadochokinesis were evaluated more extensively, since norms for these types of S-DDK are usually reported in existing research.

Firstly, material that evaluates tongue and lip diadochokinesis in consonant-vowel syllables (CV) was compiled. Secondly, material that evaluates tongue and lip diadochokinesis in CVCV-syllable sequences (two-place articulation) and CVCVCV-syllable sequences (three-place articulation) was compiled. By using material of increasing length a *complexity factor* was created, which provided interesting information about the child's ability to adapt temporal and spatial aspects of speech movements to varying contexts. In addition, the material for two and three-place articulation was varied with respect to syllable order. This was done in order to determine if a difference exists in the diadochokinesis of syllable sequences of equal length, but which varies in terms of the sequence of *place* of articulation in the mouth (e.g. front-to-back articulation, back-to-front articulation etc). The material compiled for the test battery and a description of some target movements involved in one production of the target utterance, are outlined in Table 3.5. A *Test/Recording/Rating Sheet* was also compiled (See Appendix C).

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

TABLE 3.5: MATERIAL COMPILED FOR SUB-AIM THREE

AREA	TARGET & DESCRIPTION OF ONE PRODUCTION OF THE TARGET UTTERANCE
1. Velar diadochokinesis (VDDK)	
Velar closing and opening in a CVCV-utterance (nasal- non-nasal environment)	* Repeated productions of **[də-nə]**. * The velum is closed for non-nasal [d] and [ə], then opened for nasal [n] and again closed for the final [ə] (VDDK). In addition, the tongue tip maintains and releases alveolar contact alternately for production of [d] and [n] respectively (TDDK).
2. Glottal diadochokinesis (GDDK)	
Glottal closure and opening in a CVCV-utterance (voiced-voiceless environment)	* Repeated productions of **[pə-bə]**. * The glottis (vocal cords) are opened for the production of voiceless [p] and then closed for the following voiced [ə], [b] and [ə] (GDDK). In addition, bilabial opening and closing are also performed alternately (LDDK) for the successive production of voiceless [p] and voiced [ə] respectively.
3. Tongue diadochokinesis (TDDK)	
Tongue-tip diadochokinesis in a CV-utterance (alveolar-vowel environment)	* Repeated productions of **[tə]** * Alveolar contact is alternatively maintained and released with the tongue tip for production of [t] (TDDK). In addition, glottal opening and closing (GDDK) are also performed alternately for the successive production of voiceless [t] and voiced [ə] respectively.
Back-of-the-tongue diadochokinesis in a CV-utterance (velar-vowel environment)	* Repeated productions of **[kə]** * Velar contact is alternatively maintained and released with the back-of-the-tongue for production of [k] (TDDK), while glottal opening and closing are also performed alternately (GDDK) for the successive production of voiceless [k] followed by voiced [ə] respectively.
4. Lip diadochokinesis (LDDK)	
Lip diadochokinesis in a CV-utterance (bilabial-vowel environment)	* Repeated productions of **[pə]** * Bilabial contact is alternately maintained and released for production of [p] (LDDK). In addition, glottal opening and closing are also performed alternately (GDDK) for the successive production of voiceless [p] and voiced [ə] respectively.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

TABLE 3.5 (-CONTINUED) : MATERIAL COMPILED FOR SUB-AIM THREE

AREA	TARGET & DESCRIPTION OF ONE PRODUCTION OF THE TARGET UTTERANCE
5. Combined diadochokinesis tasks elicited in two-place articulation syllable strings (CV-CV-syllable structure)	
Front-to-back * Bilabial to velar place of articulation	* **[pəkə]** * Alternate bilabial (LDDK) and velar (VDDK) contact and release are performed. Simultaneously, alternate glottal opening and closing are performed (GDDK) for the successive production of voiceless [p] & [k] followed by voiced [ə] respectively.
Front to back *Alveolar to velar place of articulation	* **[təkə]** * Alternate alveolar (LDDK) and velar (VDDK) contact and release are performed. Simultaneously, alternate glottal opening and closing are performed (GDDK) for the successive production of voiceless [t] & [k] followed by voiced [ə] respectively.
Back-to-front *Velar to bilabial place of articulation	* **[kəpə]** * Alternate velar (VDDK) and bilabial (LDDK) contact and release are performed. Simultaneously, alternate glottal opening and closing are performed (GDDK) for the successive production of voiceless [k] & [p] followed by voiced [ə] respectively.
Back-to-middle *Velar to alveolar place of articulation.	* **[kətə]** * Alternate velar (VDDK) and alveolar (LDDK) contact and release are performed. Simultaneously, alternate glottal opening and closing are performed (GDDK) for the successive production of voiceless [k] & [t] followed by voiced [ə] respectively.
6. Combined diadochokinesis tasks elicited in three-place articulation syllable strings (CV-CV-CV- syllable structure)	
Front-to-middle-to-back * Bilabial-to-alveolar-to-velar place of articulation	* **[pə-tə-kə]** * Alternate bilabial (LDDK), alveolar (TDDK) and velar (TDDK) contact and release are performed. Simultaneously, alternate glottal opening and closing are performed (GDDK) for the successive production of voiceless [p],[t] & [k] followed by voiced [ə] respectively.
Back-to-middle-to-front * Velar-to-alveolar-to-bilabial place of articulation	* **[kə-tə-pə]** * Alternate velar (TDDK), alveolar (TDDK) and bilabial (LDDK) contact and release are performed. Simultaneously, alternate glottal opening and closing are performed (GDDK) for the successive production of voiceless [k],[t] & [p] followed by voiced [ə] respectively.
Middle-to-front-to-back * Alveolar-to-bilabial-to-velar place of articulation	* **[tə-pə-kə]** * Alternate velar (TDDK), bilabial (LDDK) and velar (TDDK) contact and release are performed. Simultaneously, alternate glottal opening and closing are performed (GDDK) for the successive production of voiceless [t],[p] & [k] followed by voiced [ə] respectively.

3.5.1.4. Material compiled for sub-aim four: Consonant clusters

All initial and final CC, and CCC-clusters that occur in the Afrikaans language were included in the test material in order to obtain comprehensive normative

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

information. The material compiled for sub-aim four is outlined in Table 3.6. A *Recording/Analysis Sheet* was also compiled (See Appendix D).

TABLE 3.6: MATERIAL COMPILED FOR SUB-AIM FOUR

Initial Consonant Clusters in Afrikaans (CC- and CCC-clusters), phonetically transcribed as elicited in the test battery	Final Consonant Clusters in Afrikaans (-CC and -CCC clusters), phonetically transcribed as elicited in the test battery
[pl] [kl] [xl] [fl] [bl] [fn] [kn] [kwə] [twə] [dwə] [sl] [swə] [sn] [st] [sk] [sm] [sp] [spl] [kr] [xr] [vr] [fr] [pr] [tr] [br] [dr] [skr] [spr] [str] *Total: 29*	[ləm] [lf] [lx] [lp] [lt] [lk] [mp] [nt] [ŋk] [ŋks] [ls] [ts] [ks] [ns] [ps] [xs] [rs] [rk] [rx] [rf] [rp] [rəm] [rt] [rts] *Total: 24*

3.5.1.5. Material compiled for sub-aim five: Word syllable structure

No material was compiled for this aim as a spontaneous speech sample was used for analysis of word syllable structure. See 3.6.6. for a description of the procedure used for speech sampling.

3.5.1.6. Material compiled for sub-aims six and seven: First-vowel duration (FVD), variability of FVD and voice onset time (VOT)

The same material was used for these aims, in order to limit the length of the test battery. Since VOT is measured in stop consonants, meaningful words containing voiced and voiceless Afrikaans stop consonants were used. Since this was a first study of VOT in Afrikaans-speaking children, material was kept short and simple with only a small amount of added contextual variety. Meaningful words (familiar to children), beginning with consonants [p], [b], [t], [d] and [k] were put in initial word position, as this position yields reliable measurements and most normative data in English reflects VOT-values measured in word-initial contexts. No words containing initial-[g] were used, since the voiceless [k]-phoneme does not have a voiced cognate in the Afrikaans language. (The only word in Afrikaans containing the voiced phoneme [g] is the word "gholf", which can be considered a 'borrowed' English word). Words were limited in length while syllable structure was limited to simple CVCV, CCVCV and CVC-structures. In

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CVC and CVCV-word pairs, the sounds following the initial stop consonant were kept similar for both cognate pairs. Three words starting with consonant clusters were selected in order to vary the context to some extent. Two words starting with voiceless [k] followed by voiced lateral and nasal consonants respectively were chosen, as well as one word starting with voiced stop [b], followed by a voiced lateral consonant. The initial vowel in each word (which was measured with regard to vowel length), was limited to neutral vowels [a] and [ə] and rounded vowel [ɔ]. One word starting with [f] was included in order to observe vowel length following a fricative consonant instead of a stop consonant (it follows that VOT was not measurable in this word). A *Recording/Analysis Sheet* was also compiled (See Appendix E). The material compiled for sub-aims six and seven is outlined in Table 3.7.

TABLE 3.7: MATERIAL COMPILED FOR SUB-AIMS SIX AND SEVEN

Transcribed Word	Afrikaans Word	English Meaning
[paki]	pakkie	packet (diminutive word form)
[baki]	bakkie	a small bowl (diminutive word form)
[tasə]	tasse	suitcases
[dasə]	dasse	ties
[tɔpi]	toppie	word used to describe the top of something (diminutive form)
[dɔpi]	doppie	the shell of something e.g. a nut (diminutive form)
[tək]	tik	to type
[dək]	dik	thick
[katə]	katte	cats
[fənəx]	vinnig	fast
[knəbəl]	knibbel	nibble
[klɔki]	klokkie	clock (diminutive form)
[blɔki]	blokkie	block (diminutive form)

3.5.1.7. <u>Material compiled for sub-aim eight: First-syllable duration (FSD) in words of increasing length</u>

As this was a first study of segmental duration (i.e. of the first syllable) in Afrikaans-speaking children, material was chosen to be relatively simple with only a small amount of added contextual variety. Meaningful words (familiar to children), starting with consonant sounds that vary in terms of place of articulation (e.g. bilabial, labiodental, mid-alveolar and velar place of articulation) and manner of articulation (e.g. stop, nasal, lateral and fricative manner of articulation) were used. Words with 'expansion' possibility were selected, as the material had to be of increasing length. The first syllable (CV/CCV-unit) of each word in a specific group (of three words) remained constant e.g. [pa] remained constant in [pan], [panə], [panəkuk]. The vowels in the first syllable varied with regard to *place of constriction* (with reference to the roof of the mouth, e.g. front, central or back), with regard to *position of the tongue* (with reference to the degree of constriction in the speech channel e.g. high or low), and in terms of *lip position* (rounded, neutral or spread). A *Recording/Analysis Sheet* was also compiled (See Appendix F). The material compiled for sub-aim eight is outlined in Table 3.8.

TABLE 3.8: MATERIAL COMPILED FOR SUB-AIM EIGHT

Transcribed Word	Word Group (Wg) Number	Afrikaans Word	English Meaning
[tæl] [tæləŋ] [tæləfo:n]	1	tel telling telefoon	count score telephone
[bak] [baki] [bakərəi]	2	bak bakke bakkery	bowl bowls bakery
[duk] [dukə] [duksakə]	3	doek doeke doeksakke	diaper diapers diaper bag
[pan] [panə] [panəkuk]	4	pan panne pannekoek	pan pans pancakes
[blɔm] [blɔmə] [blɔmbakə]	5	blom blomme blombakke	flower flowers flower pots
[kɔp] [kɔpis] [kɔpici]	6	kop koppies koppietjie	head cups small head (diminutive form)
[knɔp] [knɔpə] [knɔpici]	7	knop knoppe knoppietjie	bump bumps small bump (diminutive form)
[ləp] [ləpə] [ləpstəfi]	8	lip lippe lipstiffie	lip lips lipstick
[man] [manə] [manici]	9	man manne mannetjie	man men small man (diminutive form)
[fən] [fənə] [fənəx]	10	vin vinne vinnig	fin fins fast

3.5.2. APPARATUS

3.5.2.1. Recording instruments

A VHS video camera and VHS video cassettes (SKC-180) were used for *visual* recording of each evaluation session, while the following instruments were used for *audio* recording of each session:
- Unipex Dynamic microphone
- BASF (SKC) - Chrome CD 60 audio cassettes
- Nakamichi 550 "Versatile stereo cassette system"

3.5.2.2. Measurement instruments

The data for sub-aims three, six, seven and eight were acoustically analyzed by using a digital signal processor (DSP) of the Kay Elemetrics Corp., (i.e. DSP Sona-Graph Model 5500). The Kay Sonagraph enables the listener to listen repeatedly to parts of the speech sample and to make temporal measurements by means of its digital memory. It further provides a simultaneous display of both a waveform and spectrogram of the speech signal, which allows for comparison and thus more reliable measurement. Two different settings were used. The setting for sub-aim three was similar to that of sub-aims six, seven and eight, except for a broader time axis (8sec in comparison to 1sec). This broader time axis allowed a display of more productions on the screen, which eased counting of the number of productions. Printouts of the spectrographic settings are provided in Appendix G.

3.6. DATA COLLECTION AND RECORDING PROCEDURE

3.6.1. GENERAL PROCEDURE FOLLOWED DURING DATA COLLECTION

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Each evaluation session took place in a soundproof therapy room at the University of Pretoria, in order to ensure that noise did not interfere with the recorded speech signal. *Audio* and *visual* recordings of each complete evaluation session were made (i.e. of the subject's performance on the whole test battery). The test battery was administered over an approximate 90-minute time-period, depending on the child's level of cooperation and exhaustion. The examiner and subject were both seated at a child-high table during the evaluation, in order to control the subject's movement and to allow for an acoustically reliable speech sample. The parent/s were seated behind a one-way mirror in order not to distract the child. In two cases subjects refused to separate from their mothers. For the sake of good co-operation and a representative sample, it was decided in these two cases to allow the mothers to remain in the therapy room. However, the mothers were carefully instructed not to talk to the subject or therapist during the session. Good co-operation in this regard was obtained from both mothers and representative speech samples were collected from both these subjects.

At the beginning of the session each subject was familiarized with all the recording apparatus in the room. The examiner for example, allowed the subject to observe the video camera closely and to touch the microphone. This was found to be very helpful in assuring that the apparatus did not distract the subjects during testing. The microphone was placed on a stand on the table, approximately 30cm from the subject. At the beginning of the session the examiner explained to the subject that he/she was not allowed to touch the microphone or tape recorder during the remaining of the session. The subject was encouraged throughout the evaluation to talk at normal intensity levels and to not shout or whisper. The examiner monitored the quality of the recording by frequently referring to the VU-meter on the tape recorder. The video camera was placed on a stand as not to interfere with the child's concentration.

During all data collection procedures a playful and encouraging attitude was maintained by the investigator in order to elicit good cooperation and to collect a representative data sample. Subjects were frequently verbally rewarded for attempts and after certain tests of the battery were completed successfully,

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

subjects were rewarded with small stickers in order to encourage continuing good co-operation.

The material was elicited more or less in the following sequence: sub-aims one, two, three, four, five, six, eight and seven. However, the examiner remained flexible in varying between material if the child's concentration called for it. Breaks were frequently provided according to the child's exhaustion level in order to prevent exhaustion from interfering with co-operation. During the evaluation, preliminary notes regarding responses were made on the prepared test and recording forms for each subject. However, the test forms for each subject were only formally completed after the examiner had listened to the audio-recording and had analyzed the visual recording made for each subject.

3.6.2. PROCEDURE FOR ELICITING DATA FOR SUB-AIM ONE: NON-SPEECH ORAL MOVEMENTS (NSOM)

For the elicitation of isolated non-speech oral movements (I-OM), the subject was verbally instructed to execute each of the tasks. The examiner used the instruction "I want you to do this...(followed by the tasks in Table 3.3.)". In general the examiner did not model any of the requested tasks, as they are clear and simple in nature. However, if a subject asked for modeling, it was provided. Subjects were not allowed to practice or monitor their productions in a mirror or in the one-way glass in the therapy room, as this would have allowed for additional visual feedback.

With regard to the elicitation of two and three-sequence non-speech oral movements (2S-OM and 3S-OM), the subject was verbally instructed to execute each task. Instructions were kept short and simple. These tasks were also visually demonstrated, as Bernstein (1980) found that even normal five to six-year-olds needed visual demonstration in order to execute three-step oral volitional movements. The examiner used the following instructions: "I'm going to ask you to do different things with your mouth, cheeks, lips and tongue. First I will tell you what to do and then I will show you how to do it". An example was first

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

practiced with the subject e.g. "Bite your lip and stick out your tongue. Like this....(followed by the examiner demonstrating) Now you try and do it.". The examiner only proceeded with the test items when it was apparent that the subject understood the procedure completely.

If a subject indicated during testing that he/she forgot the instructions, the examiner provided key words (refer to Table 3.3.). These key words were found very helpful in aiding recall of commands, especially with three-sequence tasks, which were linguistically somewhat complex. Implementing key words in the procedure was regarded acceptable, since the sub-aim for this set of data was to determine the ability to execute and sequence non-speech oral movements and not to test auditory memory skills.

3.6.3. PROCEDURE FOR ELICITING DATA FOR SUB-AIM TWO: NON-SPEECH ORAL DIADOCHOKINESIS (NSO-DDK)

For the elicitation of NSO-DDK the subject was verbally instructed to execute each of the tasks. The examiner used the following instructions: "I'm going to ask you to do different things with your tongue, lips and jaw. First I will tell you what to do and then I will show you how to do it". An example was first practiced with the child e.g. "Bite your lip over and over again. Like this....(followed by the investigator demonstrating). Now you do it until I say stop". The investigator tried to elicit a continuous production of the target movement for a period of at least five seconds. This time-period was found to provide an adequate sample for rating purposes. The examiner proceeded to the test items when it was apparent that the subject completely understood the procedure.

The examiner provided initial verbal key words in order to facilitate production (e.g. "left-right, left-right" and "in-out; in-out"). This was only continued for a limited time-period (about three repetitions) until it was clear that the subject understood the command, since the examiner did not want to interfere with the natural rhythm of production.

3.6.4. PROCEDURE FOR ELICITING DATA FOR SUB-AIM THREE: SPEECH DIADOCHOKINESIS (S-DDK)

Speech diadochokinesis tasks were elicited as follows. It was expected that the subjects (especially the younger ones) would experience problems to maintain the target production for a time-period of eight full seconds due to attention problems and/or exhaustion. In order to keep their interest and to elicit a good measurable sample, a game was used where plastic animal figurines were running a pretend race on a toy racing track. The subject was allowed to choose a contestant (animal) from a toy box (a different animal for each target utterance). It was explained to the subject that the animal could only run in the race while he/she maintained the production of the target utterance. The examiner manipulated the toy figurine. The subject was asked to start producing the target utterance when the examiner said "Go !". A miniature stop sign was put at the end of the racing track and the subject was asked to continue production until the animal reached the stop sign. The examiner timed the productions with a stopwatch. Eight seconds of productions were elicited in order to ensure that five full seconds of productions were available for analysis.

The whole procedure was practiced thoroughly with examples until the examiner was convinced that the subject fully comprehended the procedure. The instructions given were as follows: "You are going to help each animal to complete the race. Each animal can only run while you say the word I tell you to say. Let's practice with the dog. Let's pretend I ask you to say 'mie-mie-mie-mie'. What do you have to say ? (allowed time for the child to answer). That's right. When I say "begin" you have to start saying "mie-mie-mie" until I say stop. The dog will only run as long as you say mie-mie-mie. If you stop speaking, the dog will also stop running. Let's practice it now. Say 'mie' until I say stop. Begin !".The target syllables were elicited randomly and the same

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

random order of presentation was used with all the subjects. If the subject had trouble producing the target sequence, the examiner modeled it twice.

3.6.5. PROCEDURE FOR ELICITING DATA FOR SUB-AIM FOUR: CONSONANT CLUSTERS

The subject was verbally instructed to repeat the consonant cluster that the examiner modeled e.g. "Please say [kr]". Material was elicited in random fashion and the same random order of presentation was used with all the subjects. Each subject was told in advance that he/she was going to say sounds and that some will sound 'odd'. In spite of this 'warning', consonant clusters still proved to be difficult to elicit. The subjects apparently regarded the clusters as 'odd'-sounding utterances. Sometimes they laughed or just asked a little puzzled "What ?". The examiner gave a maximum of two repetitions of a target utterance if the child didn't produce it after the first presentation for whatever reason. A maximum of three trial productions per subject was allowed.

Consonant clusters were modeled exactly as transcribed in the material. No schwa-vowel was inserted between consonants in the cluster (eg. [br] and not [brə] or [bər]), as addition of the schwa-vowel would have changed the syllable structure of the utterance to include a vowel (thus a CVC instead of a CC-unit). Thus, it would not have allowed for the production of two and three successive consonants respectively. However, in the case of clusters 'kw', 'tw', 'dw', 'sw', 'lm', and 'rm', the schwa-vowel was inserted. These clusters were thus elicited according to their 'natural' manner of production (i.e. [kwə, twə, dwə, swə, ləm, rəm]).

3.6.6. PROCEDURE FOR ELICITING DATA FOR SUB-AIM FIVE: WORD SYLLABLE STRUCTURE

Spontaneous speech was elicited in a variety of sampling conditions namely free play, stories and routines as well as interview and scripted conditions. See Shriberg and Kwiatkowski (1985) for a detailed description of conditions. This

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Shriberg and Kwiatkowski (1985) for a detailed description of conditions. This ranged from no control of content, to indirect and direct control of content. All were sampling conditions found by Shriberg and Kwiatkowski (1985) to render a productive, intelligible and representative speech sample. A 30-minute spontaneous speech sample was elicited by means of storytelling and retelling, picture description, eliciting comments while paging through picture books (scripted condition) and during spontaneous play with a variety of toys. The same materials (e.g. storybooks, picture sequence cards and toys) were used with all the subjects.

In addition the examiner also tried to elicit talking from the subject about topics related to his/her experiences, in order to allow for creativity and individuality (i.e. interview condition). Clues to possible topics were gathered from the parent interview e.g. information about family members and siblings, family or school-related events from the past or coming in the near future (e.g. holidays, visits, outings, birthdays) or special interests the subject had. The examiner showed flexibility by alternating among sampling conditions as necessary to obtain and maintain the subject's interest in talking, a procedure found by Shriberg and Kwiatkowski (1985) to increase productivity.

3.6.7. PROCEDURE FOR ELICITING DATA FOR SUB-AIM SIX: A) FIRST VOWEL DURATION (FVD), B) VARIABILITY OF FVD, AND SUB-AIM SEVEN: VOICE ONSET TIME (VOT)

Repetitions were elicited in a simple game-context developed by the examiner. Six finger-puppets were mounted on a colorful box (the subject was involved in putting them in their places), and the subject was asked to repeat each word that the examiner says to each puppet. This simple and short procedure worked very well. It also allowed the examiner to manipulate the time-interval between repetitions by pointing to each puppet as the subject was instructed to say the word only when the examiner pointed to a particular puppet. This ensured more

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reliable acoustic measurements as the beginnings and ends of repetitions did not overflow.

Initially test trials were done with test words such as [baba], until the examiner was satisfied that the subject understood the procedure. The examiner then proceeded by saying "I want you to say....(test word). What do you have to say ?" (then waited for a response). If the subject answered correctly the examiner continued immediately by saying "Start" while pointing to the first puppet. If the subject forgot the test word the examiner repeated the instruction. However, it was found that very little repetition was needed during testing.

Six trials of every word were elicited as it was thought to be enough trials for the observation of possible variability and secondly, because it was thought that the subjects would lose concentration if more repetitions were demanded. In addition, six trials allowed for reliable samples of at least the first five repetitions. It was found that the subjects constantly produced the sixth test word with a different inflection (e.g. with falling intonation and with decreased loudness), thus not as 'thorough' as the rest of the productions. For this reason the first five productions were used for analysis (see analysis procedures). Most existing research regarding variability in children's speech suffice with five measured repetitions. Test words were presented in random order and the same order of presentation was used with all the subjects.

3.6.8. PROCEDURE FOR ELICITING DATA FOR SUB-AIM EIGHT: FIRST-SYLLABLE DURATION (FSD)

The subject was asked to repeat each target once, as modeled by the examiner. Words were produced randomly and the same random order of presentation was used with all the subjects. If the response was not acceptable for analysis (e.g. produced too animated, too fast or too loud), the examiner explained to the subject why the production was not acceptable and it was then re-elicited immediately.

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3.7. DATA ANALYSIS PROCEDURE

3.7.1. GENERAL PROCEDURE FOLLOWED

Data analysis was performed by using the live audio and video recordings of each subject's performance on the complete test battery. These recordings allowed for repetitive analysis of data and enhanced the overall reliability of scoring and analysis procedures and phonetic transcriptions. In addition, objective, acoustic analysis procedures were used in the data analysis for sub-aims four, seven and eight. In order to increase reliability further, experts were consulted in the development of the rating scales and the construction of the analysis procedures for each aim. These experts also served as second examiners in problematic cases of analysis. Repeated analysis of samples of the data performed by the examiner increased reliability further. Specific measures taken to increase the reliability of the data analysis procedures for specific aims will be discussed under the following headings.

3.7.2. COMPILATION OF RATING SCALES USED FOR DATA ANALYSIS OF SUB-AIMS ONE, TWO AND THREE: NON-SPEECH ORAL MOVEMENTS (NSOM), NON-SPEECH ORAL DIADOCHOKINESIS (NSO-DDK) AND SPEECH DIADOCHOKINESIS (S-DDK)

The construction of these rating scales was a lengthy, step-by-step process, marked by careful consideration and repetitive analysis of data in order to increase their effectiveness and the reliability of ratings. The rating scales were developed in different stages. Firstly, each scale was constructed to include all expected behaviors in the execution of the different items of the sub-tests by normal subjects. The examiner also aimed to include hypothetically expected behavior of children with developmental speech disorders based on symptom data of those disorders.

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Secondly, each rating scale was used in a *pilot application analysis* of all ten subjects' data. The different behaviors on the scales were adapted and expanded as necessary. Thirdly, the modified rating scales were applied a second time to all the data, with final changes made after this second pilot rating of the data. Results were obtained by applying the *finalized rating scales* to all subject data. If some modifications to the scales were still found necessary during this stage of application, the change was immediately made and all previous data for the particular scale/s reanalyzed, based on the modified scale/s.

As the analysis process proceeded, the examiner also compiled and expanded *guidelines for analysis* to be used in the application of the rating scales. If a new guideline was added, all previously analyzed data were reanalyzed in order to increase reliability. The subject's results for sub-aims one, two and three were thus repeatedly analyzed with *increasingly refined rating scales* and *guidelines of analysis*, which increased reliability. The rating scales will be further developed, if necessary, in a future study using subjects with developmental speech disorders, in order to enhance its clinical value.

3.7.3. DATA ANALYSIS PROCEDURE FOR SUB-AIM ONE: NON-SPEECH ORAL MOVEMENTS (NSOM)

The data were analyzed visually by using the video recording. The examiner made detailed notes about each subject's behavior on compiled T*est/Recording* and *Rating Sheets* (See Appendix A), and re-observed executions in cases that proved difficult to rate. The *Rating Scale for the Evaluation of Non-speech Oral Movements* (Table 3.9) was compiled and applied to rate the nature of the displayed behavior. Target movements were rated in each category on the compiled *Rating Sheet* (See Appendix A).

Category I. Associated movements on the rating scale (Table 3.9) refers to any inappropriate accompanying, involuntary movement/s of the body or articulators. *Category II. Accuracy of Individual Movements* refers to the ability of the child to execute individual movements with adequate rate, good quality (adequate range of movement) and adequate placement. *Category III. Sequencing* refers to the ability of the child to sequence the individual movements correctly. The execution of the target movements was analyzed by assigning appropriate behavior/s (represented by alphabet letters in the scale). If more than one behavior was applicable, it was noted as such.

The ratings in Table 3.9 are self-explanatory, however, examples of analysis, which served as rating guidelines during analysis are provided in Appendix H. The examiner compiled these analysis guidelines as the rating procedure proceeded and problematic ratings presented themselves. An experienced speech language pathologist was consulted when problematic ratings occurred. All data were repeatedly re-analyzed according to the altered and/or expanded guidelines in order to increase reliability. Each subject's data were analyzed at least five times.

After the finalized rating scale for sub-aim one was applied and the data analyzed accordingly, 30% of the data for each subject were randomly re-analyzed in order to determine a reliability rating. An overall reliability rating of 94% was obtained for the final rating scale applied for sub-aim one (NSOM).

TABLE 3.9: RATING SCALE FOR THE EVALUATION OF NON-SPEECH ORAL MOVEMENTS (SUB-AIM 1)

I. ASSOCIATED MOVEMENTS	a.	b.	c.	d.	e.	f.
	No associated movement/s of body or articulators (good dissociation)	Associated movement/s of articulators (e.g. lips, tongue, mandible)	Associated movement/s of body or non-articulators (e.g. turn neck, tilt head backwards with chin up, suck cheeks in, or turn upper body)	Associated movements of body and articulators	Child used hand to assist execution of movements	Accompanied vocalization
II. ACCURACY OF INDIVIDUAL MOVEMENTS	a.	b.	c.	d.	e.	f.
	Completely accurate production of all executed movements	Slow *initiation* (long latency) but accurate movements	Slow but accurate *execution* of target movements	Some of the movements were executed inaccurately (distorted) in terms of placement (e.g. did not touch lip corners properly during tongue lateralization)	All of the movements were executed inaccurately (distorted) in terms of placement	Some of the *individual* movements were incorrect, even with key words provided. (Thus: wrong movement/s)
	g.	h.	i.	j.	k.	l.
	All movements were incorrect , even with key words provided	Successful self-correction	Groping or struggle movements of the articulators occurred	Reduced strength of movement/s (*paresis*)	No voluntary movement/s (*paralysis*)	Part of target movement/s impossible to rate due to sequencing error (e.g. child forgot one part of the utterance or deleted a movement)
III. SEQUENCING	a.	b.	c.	d.	e.	f.
	Completely correct sequencing of movements (without key word prompt/s)	Successful self-correction	Obtained completely correct sequencing, but needed *key words* before each movement (Thus: forgot sequence but could execute the individual movements with the aid of key word prompts)	Partly correct sequencing - forgot or omitted some target movements or inserted incorrect ones,- even with *key word prompts* provided	Completely incorrect sequencing, -even with *key word prompts* provided	Impossible to *rate* due to severely reduced accuracy

3.7.4. DATA ANALYSIS PROCEDURE FOR SUB-AIM TWO: NON-SPEECH ORAL DIADOCHOKINESIS (NSO-DDK)

The data were visually analyzed using the video recordings. The *Rating Scale for the Evaluation of Non-speech Diadochokinesis* (Table 3.10) was used to rate the nature of the displayed behavior. *Category I. Associated Movements* in the scale refers to any inappropriate accompanying, involuntary movements of the body or articulators. *Category II. Accuracy of Individual Movements* refers to the ability to execute individual movements with adequate rate, good quality (adequate range of movement) and adequate placement. *Category III. Sequencing* refers to the ability to sequence the individual movements correctly. *Category IV. Continuity* refers to the ability to maintain subsequent productions rhythmically.

Behavior was described on the *Test/Recording/Rating Sheet* (see Appendix B). The target movement/s were then analyzed by assigning all applicable ratings (represented by alphabet letters in the rating scale) to their execution. If more than one rating was applicable, it was noted as such. The ratings in Table 3.10 are self-explanatory and no rules of analysis needed to be compiled, since the analysis procedure was simple. However, it was noticed that the subjects would sometimes lose some accuracy due to merely a too fast execution rate. If cautioned "Do not go too fast", they were capable of maintaining good placement. In such cases subjects were not penalized in terms of *Accuracy (II)*.

After the finalized rating scale for sub-aim two were applied and the data analyzed accordingly, 30% of the data for each subject were randomly re-analyzed in order to determine a reliability rating. An overall reliability rating of 95% was obtained for the rating scale developed and applied for sub-aim two (NSO-DDK).

TABLE 3.10: RATING SCALE FOR THE EVALUATION OF NON-SPEECH ORAL DIADOCHOKINESIS (SUB-AIM 2)

I. ASSOCIATED MOVEMENTS	**a.** No associated movement of body or articulators (good dissociation)	**b.** Associated movement/s of articulators (e.g. lips, tongue, mandible)	**c.** Associated movement/s of body (e.g. turn neck or upper body)	**d.** Associated movements of body and articulators	**e.** Child used hand to assist execution of movements	**f.** Accompanied vocalization		
II. ACCURACY OF INDIVIDUAL MOVEMENTS	**a.** Completely accurate production of executed movements	**b.** Slow *initiation* (long latency) but accurate movements	**c.** Slow but accurate *execution* of target movements	**d.** Some of the movements were executed inaccurately in terms of place-ment (e.g. does not touch lip cor-ners during tongue lateralization)	**e.** All of the movements were executed inaccurately in terms of placement	**f.** Some of the *individual* movements were incorrect (-even with key words provided)	**g.** *All* movements were incorrect (even with key words provided)	**h.** Successful self-correction occurred
	i. Groping or struggle movements of the articulators occurred (e.g. such as those associated with oral apraxia)	**j.** Reduced strength of movement/s (*paresis*) was observed	**k.** No voluntary movement/s (*paralysis*) occurred					
III. SEQUENCING	**a.** Completely correct sequencing of movements	**b.** Successful self-correction occurred	**c.** Obtained completely correct sequencing, but needed *key words* before each move-ment (thus forgot sequence but could execute the individual movements)	**d.** Partly correct sequencing - forgot some target movements even with *key words* provided	**e.** Completely incorrect -even with *key words* provided	**f.** Impossible to *rate* due to reduced accuracy or incorrect movements		

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TABLE 3.10 (-CONTINUED): RATING SCALE FOR THE EVALUATION OF NON-SPEECH ORAL DIADOCHOKINESIS (SUB-AIM 2)

	a.	b.	c.	d.	e.	f.	g.	h.
IV. CONTINUITY	Well-sustained and rhythmic with prompt initiation	Sustained and rhythmic, but with slow execution rate	Slow initiation of production but with rhythmic, sustained production thereafter	Intermittent/arythmic	Improved with production	Deteriorated	Pause/break occurred between productions	Groping or struggle movements were observed

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

It was decided not to determine diadochokinetic rate (DDR) for these movements, since pilot analysis of DDR-analysis in these tasks was found very complex for one individual to manage (in terms of counting the number of repetitions while simultaneously keeping track of the five-second analysis-period). It was argued that therapists might find it difficult to determine DDR's in clinical settings were manpower is limited (e.g. might be easier if one therapist times the performance and one does the counting), and/or video-recording facilities are not available. Further, assessment guidelines for determining DDR in these tasks could not be obtained and age norms were found limited to children older than eight years. For the sake of clinical and practical applicability, only the rating scales were thus applied in assessment.

3.7.5. DATA ANALYSIS PROCEDURE FOR SUB-AIM THREE: SPEECH DIADOCHOKINESIS (S-DDK)

The data were analyzed by means of quantitative (acoustic) analysis and qualitative (perceptual/rating scale) analysis.

3.7.5.1. Quantitative (acoustic) analysis

The number of repetitions (i.e. trial utterances of each target syllable) produced in five seconds was counted. Five seconds were regarded as an adequate time-period, since many existing research (of English speaking subjects) reported norms (i.e. diadochokinetic rates) based on a five second or even shorter time period (Baken,1987).

The number of repetitions of each target utterance produced in the five-second time period was determined by using the waveform and spectrographic display on the Kay Sonagraph, as this allowed for easy and objective counting. A time cursor (indicating the beginning of the five-second time-period) was placed at the beginning of the first production, i.e. at the very first evidence of energy burst release (of the stop consonant) on the spectrogram. A second time cursor was used to mark the end of the five-second time-period. The number of repetitions between the two time cursors was then counted on the spectrogram and recorded in the first column of the *Test/Recording/Rating Sheet* (see Appendix C). If the final trial production in the five-second time-period was interrupted by the second time cursor (thus incomplete), it was not included in the total number of repetitions. Only complete final trial productions were thus included in the counting process.

All trial productions in the marked time period were counted, whether it was accurately produced or not. Incorrect or inaccurate productions were rated in the perceptual analysis. Any breathing interruptions during the five-second production-period were ignored, as it was found to be short in duration and considered to be part of normal speech production.

3.7.5.2. Qualitative (perceptual) analysis

After counting the number of repetitions, each of these trial productions in the five-second time-period was transcribed for perceptual analysis. No transcription problems were experienced, since all subjects produced normal speech that was intelligible and easy to transcribe. The digital memory function of the Kay Sonagraph further increased accurate transcription, since it allowed the examiner to repeatedly listen to parts of the speech signal. Care was taken to note any additional information regarding intonation, phrasing, execution rate and the number of trials the child needed to execute the target utterance.

The *Rating Scale for the Evaluation of Speech Diadochokinesis* (Table 3.11) was compiled in order to rate the nature of the displayed behavior perceptually. *Category I. Continuity* refers to the ability to maintain subsequent productions rhythmically. *Category II. Associated Movements* refers to any inappropriate accompanying, involuntary movements of the body or articulators. *Category III. Accuracy* refers to the ability to produce the individual movements of speech sound production with accurate placement, adequate range of movement and adequate speed (i.e. phonetic ability). *Category IV. Sound Structure* refers to the ability to correctly sequence target sound and syllable structures (i.e. phonological sound selection and combination).

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Each transcribed production in the five-second time-period was rated on Categories II, III and IV. These ratings were recorded and rated on the *Test/Recording/Rating Sheet* (See Appendix C). If the child for example thus produced 18 productions of the target utterance, each of the 18 trials was rated separately on these three categories. Each production was analyzed by rating all applicable descriptions (represented by alphabet letters in the rating scale) in the respective categories. If more than one description was applicable to a production, it was rated as such. The data were also analyzed visually in order to allow for complete description of the context of production and to *rate Category II. Associated Movements (II.)* on the rating scale (Table 3.11).

After each production was rated, a general rating of *Continuity (Category I)* was made, based on the nature of the whole *set* of productions in the five-second time-period. If more than one error production of the target utterance occurred, and additional judgement of general *consistency* of the error pattern was made and noted on the *Test/Recording/Rating Sheet.* If the exact same error pattern occurred, the general error pattern of the series of productions was judged as consistent. If more than one type of error pattern occurred, the series was described as inconsistent.

The behavior descriptions (ratings) in Table 3.11 are self-explanatory. Examples that were used as a set of rating guidelines during analysis are provided in Appendix I. These examples also serve as descriptions of how rating decisions were made. It is important to note that the context of production was taken into account in the rating process. Aspects such as whether it was the first trial of production or not, intonation and phrasing for example, were found to be influential in the rating process. Examples of these cases are also provided in Appendix I.

After the finalized rating scale for sub-aim three was applied, and the data analyzed accordingly, 20% of the data for each subject were re-analyzed randomly in order to determine a reliability rating. An overall reliability rating of 90% was obtained for the data analysis for sub-aim three (S-DDK).

TABLE 3.11: RATING SCALE FOR THE EVALUATION OF SPEECH DIADOCHOKINESIS (SUB-AIM 3)

I. CONTINUITY (of the whole 5-second series of production)	a.	b.	c.	d.	e.	f.	g.	h.	i.
	Well-sustained and rhythmic with prompt initiation	Sustained and rhythmic, but with slow execution rate	Slow initiation of production but with rhythmic, sustained production thereafter (e.g. repetition of initial sound syllable)	Mildly intermittent/ arythmic (e.g. due to self-correction or a syllable addition in the middle of the series)	Severely intermittent or arythmic	Improves with production	Deteriorates with production	Pause/break between syllables of target production	Groping or struggle movements interfere with continuity
II. ASSOCIATED MOVEMENTS	a.	b.	c.	d.	e.				
	No associated movements of body/ articulators	Associated movement/s of articulators	Associated movement/s of body (e.g. involuntary finger spreading)	Associated movement/s of body *and* articulators	Child uses voluntary action (e.g. hand/s) to assist production				
III. ACCURACY	a.	b.	c.	d.	e.	f.	g.	h.	i.
	Completely *accurate* sound production	Slow but *accurate* execution of target utterance	Accuracy deteriorates with production	Voicing error	"Freezing" occurs (e.g. range of movement/s production decreases)	Mild phonetic *inaccuracy* (of a vowel or consonant)	Severe phonetic *inaccuracy* (of several vowels and/or consonants)	Extreme lengthening of sound/syllable	Reduced strength (*paresis*)
	j.	k.							
	No voluntary movement/s (*paralysis*)	No production							

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TABLE 3.11 (CONTINUED): RATING SCALE FOR THE EVALUATION OF SPEECH DIADOCHOKINESIS (SUB-AIM 3)

IV. SOUND STRUCTURE	a.	b.	c.	d.	e.	f.	g.	h.	i.
	Completely correct sound structure	Successful self-correction without prompting	Substitution with a sound/syllable in target utterance	Substitution with a sound/ syllable *not* in target utterance	Sound/syllable addition (at beginning or end of target utterance)	Insertion of sound/syllable (between sounds of target utterance)	Sound/syllable deletion	Sound/syllable repetition	Perseveration
	j.	k.	l.						
	Transpositio-ning of sound/s or syllable/s	Multiple changes in phoneme structure (totally incorrect)	No production						

3.7.6. DATA ANALYSIS PROCEDURE FOR SUB-AIM FOUR: CLUSTER PRODUCTION

The subject's production of each target cluster was transcribed from the audio-recording on to the *Recording/Analysis Sheet* (Appendix D). All productions were also checked visually (using the visual recording) to rate articulatory placement for target sound productions. Only productions that were produced exactly similar to the target production and with correct articulatory placement, were considered correct. For example, production of target [kl] as [kəl] was marked incorrect because of the insertion of the schwa vowel, which was not modeled by the examiner. Any errors in production were phonetically transcribed. Each subject was allowed a maximum of three trials of the target cluster. If the subject managed to produce the target sound correctly only once during these three trials, the overall performance was still rated as correct for that specific target. Perceptual analysis of any occurring error productions was also performed and will be described individually and qualitatively in Chapter 4.

After the final analysis for all the subjects was completed, ten percent of each subject's data were re-analyzed to determine a reliability rating. An overall reliability rating of 97% was obtained for sub-aim four (cluster production).

3.7.7. DATA ANALYSIS PROCEDURE FOR SUB-AIM FIVE: WORD SYLLABLE STRUCTURE

Fifty speaking turns of each subject were phonetically transcribed by listening to the audio-recordings of their spontaneous speech samples. Each speaking turn was repeatedly listened to (i.e. at least three times), in order to ensure that a reliable transcription was made. Since all the subjects produced intelligible speech, no problematic transcriptions occurred.

A speaking turn was defined as *a continuously, uninterrupted group of words, phrases or sentences produced by the subject*. A speaking turn thus did not necessarily refer to a single sentence or word (utterance). In some cases a

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speaking turn consisted of more than one complete sentence and/or phrases and in other cases of only a few words. The subjects produced an average of 524 words per 50 speaking turns, which was considered a representative number of utterances. Traditionally, samples containing 50 to 100 words are considered representative for speech analysis (i.e. articulation and phonological analysis) (Lowe,1994).

Throughout transcription *assimilation* and *coarticulation* were accommodated e.g. if the child produced two words such as [fiœlə fiɛt] as [fiœlət] or [bre:k di] as [bre:ki], it was transcribed as such (i.e. one word and not two), which implicates that the syllable structure for those words would be CVCVC and CCVCV respectively.

After phonetic transcription the syllable structure of each transcribed word was analyzed e.g. [vɔrtəls]-syllable structure: CVCCVCC. Afrikaans *diphthongs* were indicated as VV in the analysis (e.g. [fiəi] - syllable structure: CVV, [ma:ici] - syllable structure: CVVCV), since it can be argued that slight changes in tongue (and/or lip) activity/shape or other articulatory gestures (i.e. changes in the vocal tract) are involved in their production. A diphthong can be described as "...a blending of two or more vowels in the same syllable." (Lane & Molyneaoux,1992:6). Borden and Harris (1980:108) stated that "Muscle use for diphthongs is similar to that for vowels except contractions sometimes gradually shift to another muscle group.". Ohde and Sharf (1992:44) stated that "A diphthong is produced by shifting from the position for one vowel to another in the same syllable.", also implying the involvement of more than one articulatory gesture. From a sensorimotor point of view it can be argued that diphthong production requires 'more complex' changes in the vocal tract than that of single vowel production. However, it is also recognized that these articulatory shifts are almost "...continuous in fashion..." (Borden & Harris, 1980:108), that it occurs within "...the same syllable..." (Ohde & Sharf,1992:44), that a diphthong is "...a vowel of changing resonance." (Borden & Harris,1980:107), and that in phonetic analysis, diphthongs are generally noted as V (e.g. Ohde & Sharf,1992:29).

Vowels e.g. [y], [æ] and [ø] were indicated as V while affricate [tʃ] was regarded as 'C', since "An affricate is simply a stop with a fricative release." (Borden & Harris,1980:122). *Hyphenated* Afrikaans words such as [xəu-xəu] were regarded as one word, with the syllable structure thus being CVVCVV. In contrast to procedures followed in the determination of mean length of utterance (MLU) for example, natural occurring interjections, exclamations and/or word repetitions such as [ə]=C; [əm]=VC and [ɛn, tu, tu,] = VC, CV, CV were transcribed exactly as it occurred, and were also included in the syllable structure analysis.

A second transcriber (with many years of experience as phonetician) transcribed and analyzed the word syllable structures of ten utterances of each child (a mean of 130 words p/child, or approximately 25% of each subject's complete sample). An inter-judge percentage of transcription agreement of 96% was obtained.

3.7.8. DATA ANALYSIS PROCEDURE FOR SUB-AIM SIX: A) FIRST-VOWEL DURATION (FVD) AND B) VARIABILITY OF FVD

The segmental duration of the first vowel in every target word (FVD) was measured acoustically (in seconds and then converted to milliseconds-ms) for each target set of consecutively produced utterances, by using a combination of the wave form and spectrographic display. First-vowel duration was determined by placing a time cursor at the beginning of the vowel. The beginning of the vowel was indicated by the beginning of periodicity on the *waveform* and/or beginning of significant formant energy on the *spectrogram* respectively. Another time cursor was placed at the end of the vowel, which was marked by the ending of periodicity on the *waveform* and/or the ending of significant formant energy on the spectrogram respectively. In instances where the formant energy was drastically reduced, such portions were still included in the measurement of vowel duration and the very *end* of energy on the waveform taken as the end of the vowel. Measurement is illustrated in the spectrogram in Figure 3.1.

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In certain productions of the three words with target clusters (i.e. [knəbəl], [klɔki] and [blɔki]), subjects inserted a schwa-vowel (i.e.[ə]) between clusters, pronouncing it for example as [kəlɔki]. In such cases duration of the originally intended to be measured vowel (which would be [ɔ] in this example) was measured, and not the first occurring vowel [ə], since this was an insertion. All such deviations from the intended target were transcribed and noted in the results. This measurement is illustrated in the spectrogram in Figure 3.2. In instances where FVD-measurement was questionable for some reason, a second examiner (a speech scientist with ten years experience in acoustical analysis of speech) was consulted and the FVD determined by means of consensus. The first examiner re-analyzed a 10% sample of the FVD-data as an intra-examiner reliability check. All of the repeated FVD-measurements agreed within 1ms of the first measurement.

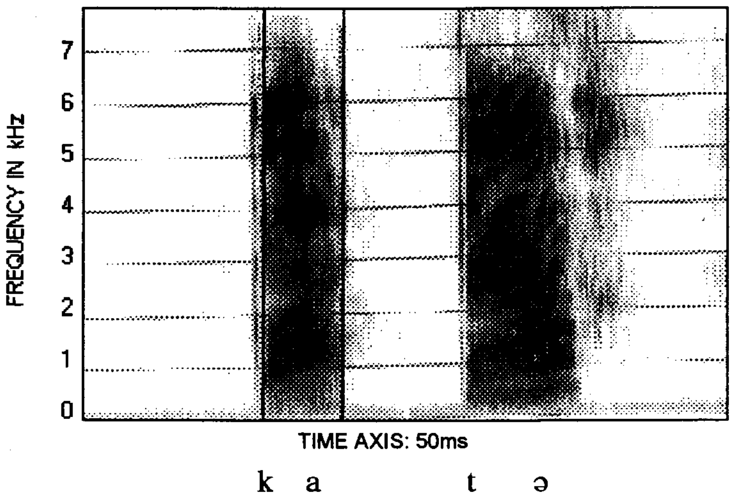

FIGURE 3.1: SPECTROGRAM ILLUSTRATING MEASUREMENT OF FIRST-VOWEL DURATION, FIFTH PRODUCTION OF [katə] BY S1, DURATION OF [a] = 122ms

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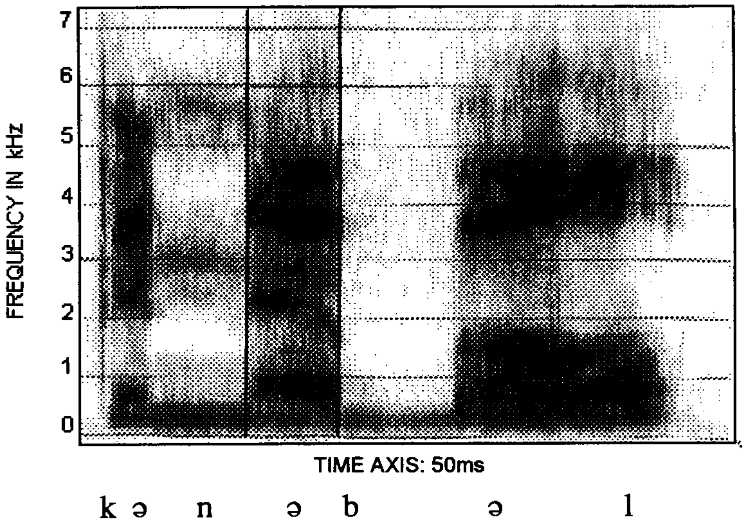

FIGURE 3.2: SPECTROGRAM ILLUSTRATING MEASUREMENT OF FIRST-VOWEL DURATION, FOURTH PRODUCTION OF [kənəbəl] BY S7, DURATION OF SECOND [ə] = 147ms

3.7.9. DATA ANALYSIS FOR SUB-AIM SEVEN: VOICE ONSET TIME (VOT)

VOT's were measured in word-initial stop consonants (thus in all words of the material compiled for sub-aim seven except the word [fənəx]). A combination of a waveform and spectrogram were used, together with the following measurement procedure. In order to determine VOT a time cursor was firstly placed at the start of the energy burst (indicating closure release). A second time cursor was then placed at the start of vocalization (at the first sign of periodicity) which either lead or followed the energy burst. The measurement between the two cursors was taken as the VOT.

Voicing lead (where voicing started before the energy burst) was indicated with a negative value (illustrated in Figure 3.3) and *voicing lag* (where voicing followed the energy burst) was indicated with a positive value (illustrated in Figure 3.4). In instances where the VOT-measurement was questionable for some reason, the second examiner was consulted and the VOT then determined by means of consensus. The examiner re-analyzed a 10% sample of the VOT-data as an intra-

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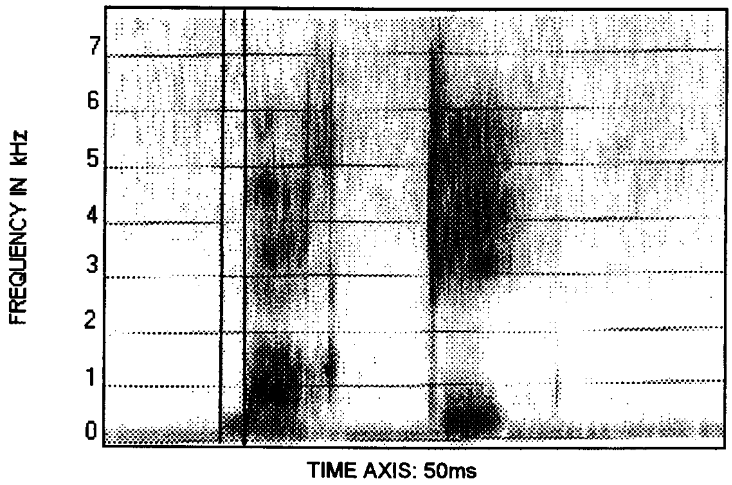
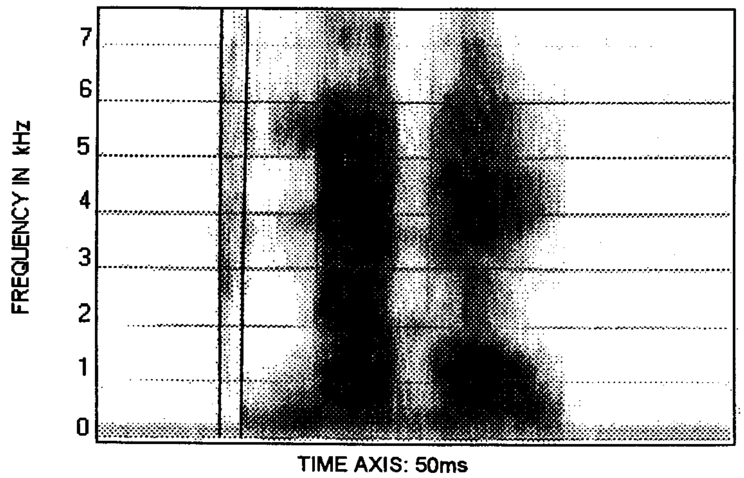
examiner reliability check and all of the repeated VOT-measurements agreed within 1ms of the first measurement.



b a k i

FIGURE 3.3: SPECTROGRAM ILLUSTRATING MEASUREMENT OF NEGATIVE VOT, SECOND PRODUCTION OF [baki] BY S3, VOT for [b] = -36ms



k n ə b ə l

FIGURE 3.4: SPECTROGRAM ILLUSTRATING MEASUREMENT OF POSITIVE VOT, FIRST PRODUCTION OF [knəbəl] BY S3, VOT for [k] = +34ms

3.7.10. DATA ANALYSIS PROCEDURE FOR SUB-AIM EIGHT: FIRST-SYLLABLE DURATION (FSD)

The first syllable (CV/CCV-unit) duration of each target word was measured acoustically by the combinatory usage of a waveform and spectrogram. A time cursor was placed at the beginning of the initial consonant. In the case of target words starting with *plosives* (i.e. stop consonants [p], [b], [t], [d], [k]) the time cursor was placed at the beginning of the energy burst (indicating closure release), since it is difficult to detect the closure phase (pressure build-up) of the plosive spectrographically. In instances where subjects produced *negative VOT's*, the cursor was placed where voicing started (negative VOT's were thus included in the final FSD-value). In the case of target words starting with *fricative*-sound [f], the time cursor was placed at the beginning of fricative noise. With target words starting with *continuant* sounds i.e. [l] and [m], the time cursor was placed at the beginning of formant energy (periodicity).

Another time cursor was then placed at the end of the first vowel (i.e. where periodicity decreased significantly). In cases where the CV/CCV-syllable was followed by a voiced continuant (e.g. [tæl] or [fən]), this time cursor was placed at the beginning of significant change in the energy of formant one (F1) and formant two (F2). The duration of the first CV/CCV-syllable was thus taken as the time interval between the two time cursors. This measurement is illustrated in Figure 3.5. If subjects inserted schwa-vowel [ə] between the consonants in words starting with clusters e.g.[kənɔpə], the schwa-vowel portion was included in the CV/CVV-measurement and noted in the results. The duration of the total CV-unit was thus still measured in these cases (illustrated in Figure 3.6.).

In instances where FSD-measurement was questionable for some reason, the second examiner was consulted and FSD then determined by means of consensus. The examiner re-analyzed a 10% sample of the FSD-data as an intra-examiner reliability check. All of the repeated FSD-measurements agreed within 1ms of the first measurement.

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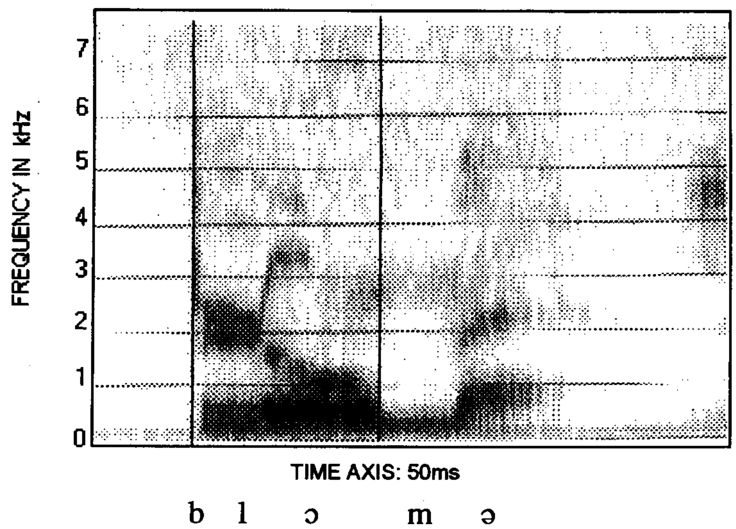

FIGURE 3.5: SPECTROGRAM ILLUSTRATING MEASUREMENT OF FIRST-SYLLABLE DURATION (FSD), PRODUCTION OF [blɔmə] BY S4, FSD of [blɔ] = 294ms

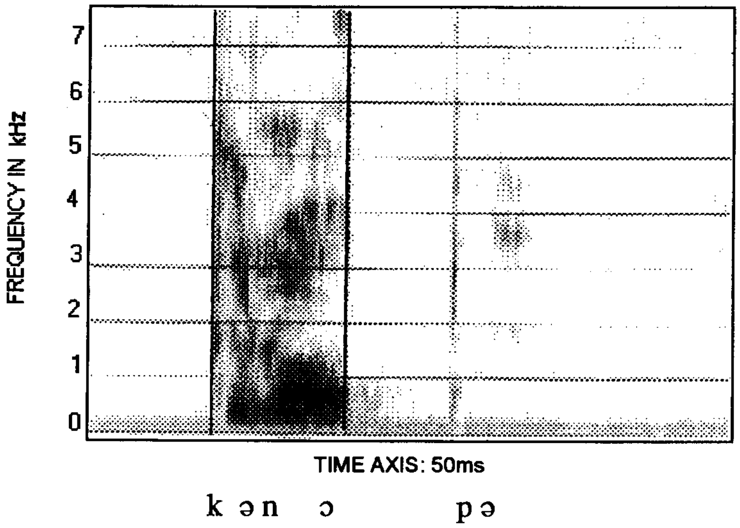

FIGURE 3.6: SPECTROGRAM ILLUSTRATING MEASUREMENT OF FIRST-SYLLABLE DURATION (FSD) WHEN A SCHWA-VOWEL WAS INSERTED, PRODUCTION OF [knɔpə] AS [kənɔpə] BY S4, FSD OF [kənɔ] = 211ms

3.8. DATA PROCESSING

3.8.1. DATA PROCESSING FOR SUB-AIM ONE: NON-SPEECH ORAL MOVEMENTS (NSOM)

The different ratings that the individual subjects obtained for the three rating scale categories (i.e. *I. Associated Movements, II. Accuracy of Individual Movements* and *III. Sequencing*) on the *Rating Scale for the Evaluation of Non-speech Oral Movements* (Table 3.9), were summarized in three different tables (Tables 4.1 to 4.3), one table for each section of the material (i.e. results for *isolated oral movements* (I-OM), results for *two-sequence oral movements* (2S-OM) and results for *three-sequence oral movements* (3S-OM). The *type* of errors that occurred is qualitatively described and discussed in Chapters 4 and 5.

3.8.2. DATA PROCESSING FOR SUB-AIM TWO: NON-SPEECH ORAL DIADOCHOKINESIS (NSO-DDK)

The *different* ratings that the individual subjects obtained for the four rating scale categories (i.e. *I. Associated Movements, II. Accuracy of Individual Movements, III. Sequencing* and *IV. Continuity*) on the *Rating Scale for the Evaluation of Non-speech Oral Diadochokinesis* (Table 3.10), were summarized in one table according to the material (Table 4.4). The *types* of errors that occurred are qualitatively described and discussed in Chapters 4 and 5.

3.8.3. DATA PROCESSING FOR SUB-AIM THREE: SPEECH DIADOCHOKINESIS (S-DDK)

In the absence of S-DDK data for Afrikaans-speaking children, data for this aim were processed in such a way that normative information could be deducted from the data. Data processing was done for both the acoustical and perceptual results obtained for this aim.

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3.8.3.1. <u>Processing of quantitative (acoustic) S-DDK-data</u>

Measurements of the *number of repetitions* each subject produced in the five-second time-period for the different S-DDK material, were firstly grouped together in the following age groups:

- data for the four-year-olds: 4;0 to 4;8 years (S1,S2,S3) (n=3)
- data for the five-year-olds: 5;0 to 5;6 years (S4,S5,S6,S7,S8) (n=5)
- data for the six-year-olds: 6;1 to 6;7 years (S9,S10) (n=2)
- data for all ten subjects together: 4;0 to 6;7 years (S1 to S10) (n=10)

The following aspects were then determined, using Microsoft-Excel (1997) for each age group and for each target word. Processed data were finally summarized according to the material (Tables 4.5 to 4.8):

♦ The ***range*** of repetitions of the target word produced in a *five-second time-period* were determined by identifying the minimum and maximum number of repetitions produced in each target group, since this would give an indication of the *boundaries* of performance that occurred (note that the word 'range' is not used here in terms of its statistical definition i.e. the difference between the maximum and minimum points in a data set)

♦ The ***mean*** number of repetitions produced in the five-second time-period was determined. *<u>Mean</u>* refers to the arithmetic mean. "The mean is what is normally called 'the average' in elementary arithmetic." (Rowntree,1981:44). The mean was calculated by "...adding together all the observed values and dividing by the number of observations." (Rowntree,1981:44).

♦ ***Individual percentage correct (PC)-scores*** were calculated which indicated the percentage of repetitions a subject produced with complete accuracy, and from this data a ***mean*** PC-score for each age group was calculated as previously described. Example: If a subject produced ten trials during the five-second time period of which only three trials were not produced with 100% accuracy the *PC-score* would be as follows: (7÷10) x 100 = 70%

- ***Diadochokinetic rate (DDR),*** which indicates *the number of repetitions per second (rep/sec),* was calculated for each group in order to make data comparable with existing age-norms. DDR's were calculated by dividing the ***mean*** number of repetitions the subjects produced in the five-second time-period by five e.g. 17/5=3.5 rep/sec. For the subjects as a group DDR's were also determined for the lowest and highest number of repetitions in five seconds, resulting in a range of DDR's for children between 4;0 and 6;7 years. For example, for [tə], the subjects as a group scored anything between 14 and 25 repetitions in the five-second period. The DDR-range will thus be (14÷5) to (25 ÷5), resulting in a *DDR-range* of 2.8 to 5 rep/sec. This implies that the subjects produced [tə] with a rate varying between 2.8 and 5 repetitions per second.

- ***Standard deviations*** for the mean rep/sec (DDR) for the subjects as a group were also calculated. The *standard deviation* is a "...way of indicating a kind of 'average' amount by which all the values deviated from the mean. The greater the dispersion, the bigger the deviations and the bigger the standard ('average') deviation." (Rowntree,1981:54). The standard deviation was calculated using Microsoft-Excel (1997). The STDEV-formula was used, which "...estimates standard deviation based on a sample." (Microsoft-Excel,1997). For example, in the previous sample the standard deviation for the subjects as a group's production of [tə] was 3.6.

3.8.3.2. Processing of qualitative (perceptual) S-DDK-data

The different ratings that the individual subjects obtained for the four rating scale categories (i.e. *I. Continuity, II. Associated Movements, III. Accuracy, IV. Sound Structure)* on the *Rating Scale for the Evaluation of Speech Diadochokinesis* (Table 3.11) were summarized in different tables according to the material (Tables 4.10 to 4.13). These tables also contain the *individual PC-scores* for each

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subject together with the *number of repetitions* a subject produced in five seconds. The general consistency of the error pattern (if any error pattern occurred) was also reported for each subject. The *type* of errors that occurred are qualitatively described and discussed in Chapters 4 and 5.

3.8.4. DATA PROCESSING FOR SUB-AIM FOUR: CLUSTER PRODUCTION

A *percentage of clusters produced correct* (PC)-*score* was determined for both sets of clusters (initial and final clusters), together with total error percentage (EP)-scores obtained by the subjects as a group for each set of clusters. The formulas used are depicted in Table 3.12. Means and standard deviations were also calculated and reported for each set of data, according to the procedure previously described in section 3.8.3.1. All this data were summarized in Table 4.14. Errors that occurred with cluster production were analyzed in terms of *error type* and *frequency of occurrence* for the subjects as a group, and are presented in Table 4.15 and 4.16.

TABLE 3.12: FORMULAS USED FOR DATA PROCESSING OF SUB-AIM FOUR

Abbreviation	*Definition of Abbreviation*	*Formula used for calculation*
PC-score for ICL	Percentage correct score for initial consonant clusters	$\frac{\text{Total Correct}}{29} \times 100$
PC-score for FCL	Percentage correct score for final consonant clusters	$\frac{\text{Total Correct}}{24} \times 100$
Total EP	Total error percentage	$\frac{\text{Total number of errors by the group}}{\text{Total number of clusters}} \times 100$

3.8.5. DATA PROCESSING FOR SUB-AIM FIVE: WORD SYLLABLE STRUCTURE

First the *frequency of occurrence* of each type of word syllable structure was counted. The different types of syllable structures were then arranged from highest to lowest frequency of occurrence. Secondly, a *percentage of occurrence* (POO) was determined for each syllable structure, based on the total number of

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utterances in the ten-subject sample. The CVC-structure for example, occurred a total of 1156 times in the ten-subject sample (the latter which consisted of a total of 5238 words). The percentage of occurrence (POO) for the CVC-structure was thus 22.1%.

Two tables were compiled to reflect the findings. In the first table all word syllable structures that occurred at least *once* in the spontaneous speech samples of *all the subjects* were included (a total of 18 different syllable structures). The total percentage of occurrence (POO) for each structure, as well as each subject's POO for each of these structures were also determined (Table 4.17). In addition, column charts of the top five syllable structures with the highest POO's were compiled as visual illustration of these data (Figure 4.1).

The second table consisted of all the word syllable structures that did not occur at least once in each subject's sample (a total of 145 different syllable structures). These structures were grouped in the table according to their percentages of occurrence (POO's) (Table 4.18).

3.8.6. DATA PROCESSING FOR SUB-AIM SIX A) FIRST VOWEL DURATION (FVD) AND B) VARIABILITY OF FVD

Data were processed according to individual and group performance.

3.8.6.1. Individual data

The *mean first-vowel duration (FVD)* and *standard deviation* for each subject's set of five productions (measured in ms) of each target word, were calculated by using Microsoft-Excel (1997) with the formulas '*Average*' to determine the *mean*, and the formula '*STDEV*' to determine the *standard deviation* (See 3.8.3.1. for definitions of these terms).

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Further, a *coefficient of variation (CfV)* was also determined for each subject's set of five productions for each target word, according to procedures described by Kent and Forner (1980), Smith et al. (1983) and Chermak and Schneiderman (1986). "The coefficient of variation (relative variability) is a more accurate measure of variability than the standard deviation when groups present different means. The coefficient of variation is calculated by dividing the standard deviation by the mean." (Chermak & Schneiderman,1986:478). The results of these individual calculations for each subject are shown in Table 4.19. Bar charts containing the individual *coefficients of variation (CfV)* for the different target words for each subject were then constructed (Figure 4.2). Mean FVD-values for each subject across target words were also determined (Table 4.23).

3.8.6.2. Age group data

Secondly, the individual subject data were grouped according to ages namely data for four-year-olds (S1,S2,S3), five-year-olds (S4,S5,S6,S7,S8), six-year-olds, as well as the subjects as a group (4;0 to 6;7-year-olds). The same calculations as above were done for each *age group* i.e. *group means*, *standard deviations* (STDEV's) and *coefficients of variation* (CfV's), for each target word and also across target words (i.e. all the target words together). In addition, the ***minimum*** and ***maximum*** durations were identified, together with the ***range*** for each age group (determined by subtracting the minimum duration from the maximum duration). These data are displayed in Tables 4.20 and 4.21.

Age group performance were finally analyzed to determine which age groups were inclined to show the longest and shortest mean FVD across target words respectively, and also to determine which age groups were inclined to display the highest (most) and lowest (least) variability of first-vowel duration respectively. These data are displayed in Tables 4.22 and 4.25.

3.8.7. DATA PROCESSING FOR SUB-AIM SEVEN: VOICE ONSET TIME (VOT)

Mean VOT-values and standard deviations (STDEV's) were firstly calculated for each subject's set of five productions of each target word, using Microsoft-Excel (1997) with the formulas '*Average*' to determine the *mean* and the formula '*STDEV*' to determine the *standard deviation* (See 3.8.3.1. for definitions of these terms). These data are presented in Table 4.26.

Secondly, the individual subject data were grouped according to ages namely VOT-data for four-year-olds (S1,S2,S3), five-year-olds (S4,S5,S6,S7,S8), six-year-olds, as well as the subjects as a group (4;0 to 6;7-year-olds). VOT-results were pooled as follows:

* VOT-results for initial voiced stops [b] and [d] in [baki], [dasə], [dɔpi], [dək]
* VOT-results for initial voiceless stops [p],[t], and [k] in [paki], [tasə], [tɔpi], [tək] and [katə]
* VOT-results for voiced stop [b] in [blɔki]
* VOT-results for voiceless stop [k] in [klɔki] and [knəbəl]

The following calculations were determined for the data pooling of each age group, using Microsoft-Excel (1997):

* group mean (formula: '*Average*')
* group standard deviation (formula: '*STDEV*')
* *minimum* VOT-value that occurred for the subjects in the group (formula: 'minimum')
* *maximum* VOT-value that occurred for the subjects in the group (formula: 'maximum')
* *range* for each group (formula: 'maximum – minimum')

These results are presented in Table 4.27. Visual illustrations of the minimum, maximium and means for the age groups (in each pooled data category) were also compiled in the form of "stock"-charts using Microsoft-Excel (1997) (Figures 4.3, 4.5, 4.6 and 4.7).

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In addition, subject and group-percentages for the occurrence of *voicing lead* in words with voiced initial stops were determined (Table 4.28). For *voiceless* plosives the percentage of positive VOT-values falling in what is theoretically considered to be the *long-lag* voicing range (Lisker & Abramson,1964) was determined. This included all mean values equal to or above +40ms (see Table 2.5. for definitions of VOT-ranges).

Finally, VOT-data for *voiced stop contexts* (i.e. word-initial position and clusters) were combined and the *mean VOT-range* for the subject as a group for voiced stops, and the overall percentages of occurrence of mean *voicing lead* for voiced stops determined for the different groups. VOT-data for *voiceless stop contexts* (i.e. word-initial position and clusters) were also combined and the *mean VOT-range* for the subjects as a group for voiceless stops and overall percentages of mean *long* voicing-lag occurrences for the groups determined (Table 4.29).

3.8.8. DATA PROCESSING FOR SUB-AIM EIGHT: FIRST SYLLABLE DURATION (FSD)

Mean *durations* and *standard deviations* for the ten subjects as a *group* were calculated firstly for each word length (i.e. including all length A, B and C words respectively) and then for each word group (Wg i.e. three words of increasing length), using the Microsoft-Excel (1997) software package with the formulas 'Average' to determine the mean and the formula 'STDEV' to determine the standard deviation (See 3.9.4 for a definition of these calculations). These data are visually illustrated in Figure 4.8, 4.10 and 4.11 in Chapter 4.

The individual subject data were also grouped into age groups, namely data for four-year-olds (S1,S2,S3), five-year-olds (S4,S5,S6,S7,S8) and six-year-olds (S9,S10). The same calculations as above were done for each age group i.e. group *means* and *standard deviations* (STDEV) for all three word lengths and some word groups. These data are visually illustrated in Figures 4.9, 4.12, 4.13 and 4.14.

3.9. CONCLUSION

In this chapter the research method was presented. The selected sub-aims, together with theoretical motivations for their inclusion, definitions of terminology, as well as the research design were outlined. This was followed by a description of subject selection criteria and the procedure for subject selection, together with details of material compilation and the selection of measurement instruments. Finally, the data collection, recording, analysis and processing procedures were described in detail for each sub-aim.

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CHAPTER 4

DESCRIPTION AND DISCUSSION OF RESULTS

4.1. INTRODUCTION

In this chapter the data obtained for the different sub-aims of this study will be described and discussed separately. Data description and discussion for each sub-aim will start with an introduction of the way the data will be presented, as well as indications of applicable test/recording sheets and/or rating scales where necessary.

4.2. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM ONE: NON-SPEECH ORAL MOVEMENTS (NSOM)

The goal of this sub-aim was to investigate the ability of normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, to plan and execute *isolated (I-OM)*, *two-sequence (2S-OM)*, and *three-sequence (3S-OM) voluntary, non-speech oral movements (NSOM)* on request, by the application of a comprehensive *rating scale* designed for assessing performance on these tasks.

Performance was rated in terms of three categories on the *Rating Scale for the Evaluation of Non-Speech Oral Movements* (Table 3.9) named *I. Associated Movements*, *II. Accuracy of Individual Movements* and *III. Sequencing* (see Chapter 3 for definitions of these categories). The results for the three sections of sub-aim one i.e. *isolated oral movements* (I-OM), *two sequence oral movements* (2S-OM) and *three sequence oral movements* (3S-OM) are presented in Tables 4.1, 4.2 and 4.3. Results for these sections will first be described separately, followed by a joint summary and discussion of the results for sub-aim one.

In the following discussion, target movement numbers correspond with the numbers in Table 3.3 as well as the *Test/Recording* and *Rating Sheets* compiled for sub-aim one in Appendix A. Roman numerals (e.g. II.) refer to categories on the rating scale (Table 3.9), while lower case letters (e.g. b) refer to ratings in each category of the scale. In all categories an (a)-rating indicated that *no problems* were displayed for that category. Ratings other than (a) will be referred to as error ratings.

4.2.1. DESCRIPTION OF RESULTS FOR SUB-AIM ONE

Results will be discussed in terms of the subjects' performance on the different target movements for isolated (I-OM), two sequence (2S-OM) and three sequence (3S-OM) oral movements.

4.2.1.1. Isolated oral movements (I-OM)

The results for I-OM are depicted in Table 4.1. It can be seen that all the subjects scored (a)-ratings in all three categories of target movements 1.1 *(Blowing out a candle)* and 1.2 *(Puffing the cheeks)*, indicating that no problems occurred with the execution of these movements. For target movement 1.3 *(Licking an ice cream)* only S6, S7, S8, and S9 scored (a)-ratings in all three categories. In summary, all the subjects were thus capable of voluntary execution of I-OM, but only four subjects scored (a)-ratings across all three target-movements. The following error ratings occurred in the three categories (refer to Table 4.1 for details):

* Category I (i.e. *Associated Movements)*: Error ratings that occurred for target movement 1.3 *(Licking an ice cream)* included one (b)-rating (i.e. *Associated movement/s of the articulators*), and one (c)-rating (i.e. *Associated movement/s of the body or non-articulators)*. These ratings were the result of subjects lifting their chins upwards or tilting their heads backwards. Results thus indicated that the majority of subjects were able to perform I-OM without associated movements.

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TABLE 4.1: RESULTS FOR ISOLATED ORAL MOVEMENTS (I-OM)

SUBJECT	AGE (yrs)	RATING SCALE CATEGORIES						
		I. Associated Movements			II. Accuracy of Individual Movement/s			III. Sequencing
		a.*	b.*	c.*	a.*	d.*	f.*	a.*
1.1. Blow out a candle								
S1	4;0	*			*			
S2	4;1	*			*			
S3	4;8	*			*			
S4	5;0	*			*			
S5	5;3	*			*			
S6	5;4	*			*			
S7	5;4	*			*			
S8	5;6	*			*			
S9	6;1	*			*			
S10	6;7	*			*			
TOTAL:		*10*			*10*			
1.2. Puff cheeks								
S1	4;0	*			*			
S2	4;1	*			*			
S3	4;8	*			*			
S4	5;0	*			*			
S5	5;3	*			*			
S6	5;4	*			*			
S7	5;4	*			*			
S8	5;6	*			*			
S9	6;1	*			*			
S10	6;7	*			*			
TOTAL:		*10*			*10*			
1.3. Lick an ice-cream								
S1	4;0			*	*			
S2	4;1	*				*		
S3	4;8	*				*		
S4	5;0	*				*		
S5	5;3	*				*		
S6	5;4	*			*			
S7	5;4	*			*			
S8	5;6	*			*			
S9	6;1	*			*			
S10	6;7		*				*	
TOTAL:		*8*	*1*	*1*	*5*	*4*	*1*	

** Please refer to the Rating Scale for Non-Speech Oral Movements (TABLE 3.9) for definitions of these abbreviations*

* Category II *(Accuracy)*: Four children (S2, S3, S4, S5) scored (d)-ratings (*Some movements executed inaccurately in terms of placement*) and one (S10) an (f)-rating (*Some of the individual movements were incorrect*). Half of the subjects thus displayed some accuracy problems with upward tongue licking movements. Error performance was characterized by circular and/or in-out movements instead of upward-licking tongue movements. Some children also rested the tongue on the lower lip while performing licking movements. When inaccuracy continued to be demonstrated in the upward licking movements, in spite of demonstration and instruction, error ratings were assigned.

* Category III *(Sequencing):* Since these were isolated oral movements, sequencing was not rated.

4.2.1.2. Two-sequence oral movements (2S-OM)

The results for 2S-OM are reported in Table 4.2. It can be seen from the results that all the subjects scored (a)-ratings for target movement 2.1 (i.e. *Blow a kiss and cough*) indicating no problems with this target movement. However, for movements 2.2 (i.e. *Pout lips and lateralize tongue outside mouth from lip corner to lip corner*), and 2.3 (i.e. *Puff cheeks and lateralize tongue outside mouth from lip corner to corner)* only S3, S6 and S8 scored (a)-ratings in all three categories for these two target movements. In summary, it can thus be seen from the data in Table 4.2 that although all subjects were capable of *voluntary* execution of 2S-OM, only three subjects scored (a)-ratings across all three target-movements.

Results indicated that error-ratings for target movements 2.2 (i.e. *Pout lips and lateralize tongue outside mouth from lip corner to lip corner*), and 2.3 (i.e. *Puff cheeks and lateralize tongue outside mouth from lip corner to corner)* occurred as follows in all three categories of the rating scale:

* Category I (i.e. *Associated Movements)*: Frequent (b)-error ratings (*Associated movement/s of articulators*) and one (c)-error rating occurred. (i.e. *Associated movement/s of the body or non-articulators).*

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TABLE 4.2: RESULTS FOR TWO-SEQUENCE ORAL MOVEMENTS (2S-OM)

SUBJECT	AGE (yrs)	RATING SCALE CATEGORIES								
		I. Associated Movements			II. Accuracy of Individual Movement/s			III. Sequencing		
		a.*	b.*	c.*	a.*	d.*	f.*	a.*	c.*	f.*
2.1 Blow a kiss and cough										
S1	4;0	*			*			*		
S2	4;1	*			*			*		
S3	4;8	*			*			*		
S4	5;0	*			*			*		
S5	5;3	*			*			*		
S6	5;4	*			*			*		
S7	5;4	*			*			*		
S8	5;6	*			*			*		
S9	6;1	*			*			*		
S10	6;7	*			*			*		
TOTAL:		*10*			*10*			*10*		
2.2. Pout lips and lateralize tongue outside mouth from lip corner to corner										
S1	4;0			*		*	*	*		
S2	4;1		*			*			*	
S3	4;8	*			*			*		
S4	5;0		*			*		*		
S5	5;3		*		*			*		
S6	5;4	*			*			*		
S7	5;4		*		*			*		
S8	5;6	*			*			*		
S9	6;1		*		*			*		
S10	6;7		*		*			*		
TOTAL:		*3*	*6*	*1*	*7*	*3*	*1*	*9*	*1*	
2.3. Puff cheeks and lateralize tongue outside mouth from lip corner to corner										
S1	4;0	*					*			*
S2	4;1		*		*				*	
S3	4;8	*			*			*		
S4	5;0		*			*		*		
S5	5;3		*		*			*		
S6	5;4	*			*			*		
S7	5;4		*		*			*		
S8	5;6	*			*			*		
S9	6;1		*		*			*		
S10	6;7		*		*			*		
TOTAL:		*4*	*6*	*0*	*8*	*1*	*1*	*8*	*1*	*1*

** Please refer to the Rating Scale for Non-Speech Oral Movements(TABLE 3.9) for definitions of these abbreviations*

These errors consisted of accompanying head movement (displayed by youngest subject, S1) and frequent associated movements of the mandible. Results might have indicated a tendency for normal children between 4;0 and 6;7 years to display associated movements of the mandible in tongue lateralization tasks, since only three subjects (S3, S6, S8) showed no associated mandible movements (See Table 4.2).

* Category II (i.e. *Accuracy of Individual Movements)*: (d)-error ratings (i.e. *Some of the movements were executed inaccurately*) and (f)-error ratings (i.e. *Some of the movements were incorrect*) were displayed. Inaccurate behavior was characterized by occasional inadequate touching of the lip corners, sweeping of the tongue over the lower lip. Incorrect behavior included in-out tongue movements instead of lateralization, or lateralization movements inside, instead of outside the mouth. The majority of subjects displayed no problems in Category II, indicating that these normal children between 4;0 and 6;7 years were mostly capable of accurate execution of 2S-OM.

* Category III *(Sequencing)*: Two children (S1 and S2) displayed error ratings for 2S-OM in the form of two (c)-ratings (i.e. *Obtained completely correct sequencing but needed keywords before each movement)* and an (f)-rating (i.e. *Impossible to rate due to severely reduced accuracy)*. The (f)-rating was scored by the youngest subject (S1) on target movement 2.3 (i.e. *"Puff your cheeks and then touch your left and right lip corners fast with your tongue)*, indicating that this particular movement may be difficult to sequence for some four-year-olds. Sequencing problems for 2S-OM were thus restricted to the two youngest subjects.

4.2.1.3. Three-sequence oral movements (3S-OM)

Results for *3S-OM* are depicted in Table 4.3 and indicated that although all the subjects were capable of voluntary execution of the individual target movements, only two subjects (S4 & S6) obtained only (a)-ratings for both target movements. The following error ratings occurred for 3S-OM in the three categories:

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* Category I *(Associated Movements)*: No error ratings occurred for target movement 3.1 (see Table 4.3). Five (c)-ratings (*Associated movements of body or non-articulators)* occurred for target movement 3.2 *(Blow a kiss, touch nose with tongue, blow out a candle),* since half of the subjects tended to tilt their heads backwards and/or lifted their chins when trying to touch their noses with their tongues. It can be speculated that this could have been the result of mere effort in trying to accomplish the task. Maybe a more achievable task such as "touch your upper lip with your tongue tip" for example, would not have resulted in this behavior. However, half of the subjects did manage to execute the task without any associated movements.

* Category II *(Accuracy of Individual Movements)*: Two subjects (S2 and S10) scored (c)-ratings (i.e. *Slow but accurate execution of target movements)* and one subject a (d)-ratings (i.e. *Some of the movements were executed inaccurately in terms of placement),* while eight subjects showed no accuracy problems at all for the two target movements. It appeared as if slow execution occurred in an attempt of some children to manage the sequencing aspects of 3S-OM. The one error of inaccuracy was an instance where the subject did not perform a very well-executed upward tongue movement, but instead rested the tongue on the bottom lip for the most part of it. Accuracy thus did not appear to have been much of a problem in the execution of 3S-OM.

* Category III (Sequencing): Frequent (c)-error ratings occurred for the two target movements (i.e. *Obtained completely correct sequencing but needed key words before each movement*) and one subject scored a (d)-rating (i.e. *Partly correct sequencing -forgot or omitted some target movement or inserted incorrect ones -even with key words provided*). Six subjects scored no errors ratings with movement 3.1 and four subjects scored no error ratings with movement 3.2. The results thus indicated that some children between 4;0 and 6;7 years may experience auditory memory related problems with sequencing of 3S-OM. Syntactic processing demands could also have contributed to their problems, but the fact that the examiner modeled the target behavior, and that key words were provided, reduced this possibility. The subjects' performance usually improved as a result of the provision of key words.

TABLE 4.3: RESULTS FOR THREE-SEQUENCE ORAL MOVEMENTS (3S-OM)

SUB-JECT	AGE (yrs)	RATING SCALE CATEGORIES							
		I. Associated Movements		II. Accuracy of Individual Movements			III. Sequencing		
		a.*	c.*	a.*	c.*	d.*	a.*	c.*	d.*
3.1. Pout lips, puff cheeks, stick out tongue									
S1	4;0	*		*				*	
S2	4;1	*			*		*		
S3	4;8	*		*			*		
S4	5;0	*		*			*		
S5	5;3	*		*					*
S6	5;4	*		*			*		
S7	5;4	*		*			*		
S8	5;6	*		*				*	
S9	6;1	*		*			*		
S10	6;7	*			*			*	
TOTAL:		*10*		*8*	*2*		*6*	*3*	*1*
3.2. Blow a kiss, touch nose with tongue, blow out a candle									
S1	4;0	*		*			*		
S2	4;1		*	*				*	
S3	4;8		*	*				*	
S4	5;0	*		*			*		
S5	5;3		*	*				*	
S6	5;4	*		*			*		
S7	5;4		*	*				*	
S8	5;6	*		*				*	
S9	6;1		*	*			*		
S10	6;7	*			*	*		*	
TOTAL:		*5*	*5*	*9*	*1*	*1*	*4*	*6*	

** Please refer to the Rating Scale for Non-Speech Oral Movements (TABLE 3.9) for definitions of these abbreviations.*

4.2.2. SUMMARY AND DISCUSSION OF RESULTS FOR SUB-AIM ONE (I-OM, 2S-OM AND 3S-OM)

4.2.2.1. General findings

The categories and ratings on the compiled *Rating Scale for the Evaluation of Non-speech Oral Movements* (Table 3.9), were useful in describing and rating the behavior displayed by the normal children, providing valuable information about the characteristics of their performance on the target movements. By applying the

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rating scale, the traditional assessment of NSOM was expanded and basic normative information regarding the execution of NSOM by children in this age range was obtained. A tentative database has thus been established to which the performance of Afrikaans-speaking children with developmental speech disorders on these tasks can be clinically compared.

In summary, the results for sub-aim one indicated that all subjects were capable of voluntary execution of the individual components of all target movements in all three sections, indicating no signs of oral apraxia in these normal subjects (as expected). However, the *quality* of execution of these movements varied, indicating that normal children between the ages of 4;0 and 6;7 years can still display some minor associated movements, slight problems with accuracy and occasional sequencing problems in some areas of NSOM.

When the data in Tables 4.1 (I-OM), Table 4.2 (2S-OM) and Table 4.3 (3S-OM) were compared, it was found that only one subject, namely S6 (aged 5;4 years) scored perfect ratings (i.e. only a-ratings) in all three sections of sub-aim one. Even when the results for the three sections were separately reviewed, it was observed that only a few subjects were capable of executing *all* the target-movements of each section with perfect accuracy, sequencing and with no associated movements. For example, only four subjects (i.e. S6, S7, S8, S9, or 40% of the subjects) scored perfect ratings with I-OM, only three subjects (i.e. S3, S6, S8, or 30% of the subjects) scored perfect ratings with 2S-OM, and two subjects (i.e. S4, S6, or 20%) scored perfect ratings for 3S-OM. The finding that I-OM yielded less error ratings than 2S-OM, which in turn yielded less error ratings than 3S-OM, is much what one might predict, since it can be argued that remembering, planning and executing a series of different movements "...presumably place more demands upon the motor system than simple repetition." (Ansel et al,1992:10).

Although this is a very small study, with results only limited to the assessed tasks and categories rated, results seem to indicate the possibility that although the majority of normal children between 4;0 and 6;7 years can plan and execute non-speech oral movements, their performance are not yet adult-like in all respects.

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However, it was found that some children (although in the minority) did display more seemingly adult-like performance on the assessed tasks, indicating individual trends in performance.

4.2.2.2. Types of errors

Associated movements occurred and were characterized in the section I-OM by lifting the chin and tilting the head during upward tongue licking movements (displayed by half of the subjects). Associated mandible movements were frequently displayed in *tongue lateralization* tasks (2S-OM), with only three subjects not displaying these movements. In the section 3S-OM, the associated movement of backwards head tilting occurred in half of the subjects, but this could be interpreted as a result of effort due to the relative impossibility of the task of "touching the nose with the tongue", rather than being a true associated movement. On the other hand, half of the subjects did not display this behavior. In summary, results thus indicated that normal children between the ages of 4;0 and 6;7 years may display some possibly *task-related associated movements* (e.g. in upward tongue-licking movements or when trying to touch the nose with the tongue). Further, results seem to indicate that the majority of normal children between 4;0 and 7;0 years may still find it difficult to execute *tongue lateralization* tasks without accompanying associated movements.

Accuracy problems occurred and were characterized by problems *with upward tongue licking movements* in half of the subjects in the section of I-OM (e.g. in-out and circular movements instead of up-down movements). In 2S-OM inadequate touching of the lip corners, in-out instead of left-right tongue movements, lateralization inside instead of outside the mouth, and sweeping of the tongue over the bottom lip occurred in *lateralization* tasks but the majority of subjects was capable of accurate execution of 2S-OM. In the section 3S-OM accuracy problems only occurred in 20% of the subjects and were restricted to *slow but accurate* execution in a possible attempt to accomplish correct sequencing. Although some error ratings occurred on lateralization and upward tongue licking movements, the subjects generally did not display accuracy problems with the execution of NSOM.

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Robbins and Klee (1987) accordingly found that some 4;0 to 6;11-year-olds have not reached adult precision on oral-motor speech and non-speech movements. However, they used a simple three-point rating scale i.e. 2=adult function; 1=emerging skill (e.g. an approximation of target but lacking adult precision) and 0=absent function (e.g. no approximation of the target behavior) to judge their subjects' performance on functional tasks (e.g. lip rounding, pitch variation, tongue mobility). Their protocol did not include *sequenced* oral speech movements or descriptions of how normal children's performance deviated from what was expected to be 'normal' or 'adult-like' (e.g. whether associated movements occurred or what imprecision of movements entailed), all of which limit comparison of results.

Sequencing problems also occurred. In 2S-OM it was restricted to the two *youngest* subjects (four-year-olds) who needed key words in order to accomplish correct sequencing. However, sequencing problems occurred more profoundly with 3S-OM, where only three subjects (30%) obtained correct sequencing without any key words provided. *Auditory memory* problems seem to have contributed to sequencing errors, since most subjects were able to execute the target movements in the correct sequence when key words were provided.

Bernstein (1980) also found that Afrikaans-speaking five to six year-old children displayed problems with the execution of a three-step and some two-step non-speech oral movement sequencing tasks, and needed demonstration in order to accomplish correct sequencing. In a pilot attempt to assess volitional oral movements in children aged three to six years, Ansel et al. (1992) found that although the children could execute isolated oral movements in imitation, they had difficulty sequencing these gestures. They noted that pre-school children could only perform three-sequence pictured non-speech tasks with "...extensive rehearsal..." (Ansel et al.,1992:10) and recommended that if combinatory sequences are included in tests of NSOM, they should compromise of two items only, at least for four to five-year-old children. In the present study similar observations were made since the two four year-old subjects displayed the most problems with sequencing.

Results thus indicated that normal children aged 4;0 to 6;7 years, may still show some errors in the execution of voluntary NSOM in terms of associated movements, sequencing and accuracy, although not profound in nature. Extensive research with larger, normal subject groups is needed in order to expand these basic observations and to clarify observations.

4.3. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM TWO: NON-SPEECH ORAL DIADOCHOKINESIS (NSO-DDK)

The goal of this sub-aim was to investigate the ability of normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, to plan and execute *repetitive, non-speech movements* of the tongue, lips and jaw in *non-speech, oral diadochokinesis (NSO-DDK)*, imitative tasks, by the application of a comprehensive *rating scale* designed for assessing performance on these tasks.

Performance was rated in terms of four categories on the *Rating Scale for Non-Speech Diadochokinesis* (Table 3.10), termed *I. Associated Movements, II. Accuracy of Individual Movements, III. Sequencing* and *IV. Continuity*. The results for all four target movements are presented in Table 4.4. Performance on these movements will be jointly discussed in terms of the categories on the rating scale.

In the following discussion, target movement numbers correspond with the numbers in Table 3.4 as well as the recording/rating sheet compiled for sub-aim two (Appendix B). Roman numerals (e.g. II.) represent <u>categories</u> on the rating scale (Table 3.10), while lower case letters (e.g. b) represent <u>ratings</u> in each category of the scale.

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TABLE 4.4: RESULTS FOR NON-SPEECH ORAL DIADOCHOKINESIS

SUB-JECT	AGE (yrs)	I. Associated Movements				II. Accuracy of Individual Movements			III. Sequencing			IV. Continuity		
		a.*	b.*	c.*	d.*	a.*	d.*	f.*	a.*	c.*	f.*	a.*	b.*	d.*
1. Tongue lateralization outside the mouth														
S1	4;0				*			*			*			*
S2	4;1		*			*			*			*		
S3	4;8	*				*			*			*		
S4	5;0		*				*		*			*		
S5	5;3		*				*		*			*		
S6	5;4	*				*			*			*		
S7	5;4	*				*			*			*		
S8	5;6	*				*			*			*		
S9	6;1		*			*			*			*		
S10	6;7		*			*			*			*		
TOTAL:		*4*	*5*		*1*	*7*	*2*	*1*	*9*		*1*	*9*		*1*
2. Tongue in and out of the mouth														
S1	4;0		*			*			*			*		
S2	4;1		*				*		*				*	
S3	4;8		*			*			*			*		
S4	5;0	*				*			*			*		
S5	5;3				*		*				*			*
S6	5;4		*			*			*					*
S7	5;4	*				*			*			*		
S8	5;6		*			*			*			*		
S9	6;1	*				*			*			*		
S10	6;7	*				*			*			*		
TOTAL:		*5*	*5*		*1*	*8*	*2*		*9*		*1*	*7*	*1*	*2*
3. Lips pout and stretch														
S1	4;0			*			*		*			*		
S2	4;1	*				*			*			*		
S3	4;8	*				*			*			*		
S4	5;0	*				*			*			*		
S5	5;3	*				*			*			*		
S6	5;4	*				*			*			*		
S7	5;4	*				*			*			*		
S8	5;6		*					*			*	*		
S9	6;1	*				*			*			*		
S10	6;7	*				*				*				*
TOTAL:		*8*	*1*	*1*		*8*	*1*	*1*	*8*	*1*	*1*	*9*		*1*

** Please refer to the Rating Scale for Non-Speech Oral Movements (TABLE 3.10) for definitions of these abbreviations*

TABLE 4.4 (-CONTINUED): RESULTS FOR NON-SPEECH ORAL DIADOCHOKINESIS

SUB-JECT	AGE (yrs)	I. Associated Movements				II. Accuracy of Individual Movements			III. Sequencing			IV. Continuity		
		a.*	b.*	c.*	d.*	a.*	d.*	f.*	a.*	c.*	f.*	a.*	b.*	d.*
4. Jaw open and close														
S1	4;0	*				*			*			*		
S2	4;1	*						*			*	*		
S3	4;8	*				*			*			*		
S4	5;0	*				*			*			*		
S5	5;3	*				*			*			*		
S6	5;4	*				*			*			*		
S7	5;4	*				*			*			*		
S8	5;6	*				*			*			*		
S9	6;1	*				*			*			*		
S10	6;7		*				*				*	*		
TOTAL:		*9*	*1*			*8*	*1*	*1*	*8*		*2*	*10*		

** Please refer to the Rating Scale for Non-Speech Oral Movements (TABLE 3.10) for definitions of these abbreviations*

In all categories an (a)-rating indicated that *no problems* were displayed for that category. Ratings other than (a) will be referred to as error ratings.

4.3.1. DESCRIPTION OF RESULTS FOR CATEGORY I (ASSOCIATED MOVEMENTS)

From the data in Table 4.4 it can be seen that the most error ratings occurred with target movements one (i.e. *Tongue lateralization/wagging the tongue outside the mouth*) and two (i.e. *Tongue in and out of mouth*), with only one error rating each on target movement three (i.e. *Lips pout and stretch*) and target movement four (i.e. *Jaw open and close*). Further, the data showed that only one subject (S7) scored perfect ratings (i.e. only (a)-ratings) in all four target movements. Error ratings in terms of associated movements for the four target movements consisted of frequent (b)-ratings (i.e. *Associated movement/s of the articulators*), one (c)-rating (i.e. *Associated movements of the body*) two (d)-ratings (i.e. *Associated movements of body and articulators*). It should be noted that some subjects executed the target movements very fast, which also resulted in associated

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movements. In such cases error ratings were not assigned. When children are asked to perform these movements it is thus important to emphasize that they should "not go too fast". Results thus indicated that some normal 4;0 to 6;7 year-olds may show a tendency to perform repeated tongue movement tasks (e.g. lateralization and in-out movements) with some associated movements of other articulators.

4.3.2. DESCRIPTION OF RESULTS FOR CATEGORY II (ACCURACY OF INDIVIDUAL MOVEMENTS)

The data in Table 4.4 indicated very few error ratings in terms of accuracy. Four subjects (S3, S6, S7 and S9) obtained no error ratings in any target movement, while the rest of the subjects only occasionally displayed an error rating. The few error ratings that occurred consisted of only (d)-ratings (i.e. *Some of the movements were executed inaccurately in terms of placement*) and (f)-ratings (i.e. *Some of the individual movements were executed incorrectly*). Behavior ranged from 'in-out' instead of 'left-right' tongue movements, mouth opening which interfered with lip pout-stretch movements to chewing movements with jaw opening and closing. In general, subjects thus did not display problems with accuracy. Accuracy was sometimes reduced due to a too fast execution rate, in which instances the subjects were not penalized.

4.3.3. DESCRIPTION OF RESULTS FOR CATEGORY III (SEQUENCING)

The data in Table 4.4 indicated that sequencing errors seldom occurred. Only one (c)-rating (i.e. *Obtained completely correct sequencing but needed key words before each movement*) and a few (f)-ratings (i.e. *Impossible to rate due to reduced accuracy or incorrect movements*) were displayed by different subjects (i.e. S1, S2, S5, S8 and S10) across all four target movements. The rest of the subjects scored perfect ratings (i.e. only a-ratings) for all the target movements in Category III. Overall results thus indicated that sequencing in these simple tasks was not problematic for these normal subjects and that only occasional errors occurred.

4.3.4. DESCRIPTIONS OF RESULTS FOR CATEGORY IV (CONTINUITY)

The subjects generally performed well, with only five error ratings occurring across all subjects and target movements (see Table 4.4 for details). Error ratings consisted of occasional (d)-ratings (i.e. *Intermittent/arythmic*) and one (b)-rating (i.e. *Sustained and rhythmic but with slow execution rate*). Five subjects (S3, S4, S7, S8 and S9) displayed no error ratings in any of the target movements.

4.3.5. DISCUSSION OF RESULTS FOR SUB-AIM TWO

In summary, the majority of subjects were thus capable to perform repetitive productions of non-speech movements with good accuracy, sequencing, and continuity. However, associated movements occurred more often, since mandible movements frequently accompanied tongue lateralizations tasks (which corresponds to the findings for voluntary NSOM that was previously reported). Only one subject (S7) never displayed associated movements in any task, which may indicate a general tendency for normal children in this age range to show occasional associated movements in NSO-DDK-tasks.

It can be concluded that the categories and ratings on the compiled *Rating Scale for the Evaluation of Non-speech Oral Diadochokinesis* (Table 3.10), were useful in describing and rating the performance of these normal children. By applying this rating scale, the traditional assessment of repetitive non-speech oral movements was expanded. Basic descriptive normative information regarding the execution of these movements by normal children (aged 4;0 to 6;7 years) were obtained, to which the performance of Afrikaans-speaking children with DSD on these tasks can be clinically compared with.

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In the opinion of the examiner *behavioral descriptions* of children's performance on these non-speech diadochokinetic tasks (such as accomplished through the application of the rating scale) may firstly be more practical (i.e. easier to accomplish in a clinical setting) and secondly, may provide more descriptive information regarding symptom patterns in children with DSD, than a mere reporting of diadochokinetic rate (DDR) on these non-speech tasks would do. Unfortunately no comparative studies for this aim was identified, which limits further discussion of these results.

4.4. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM THREE: SPEECH DIADOCHOKINESIS (S-DDK)

The goal of this sub-aim was to investigate the ability of normal, Afrikaans-speaking children aged 4;0 to 7;0 years to produce repetitive speech movements in speech diadochokinesis (S-DDK) tasks, involving tongue, lip, velar and glottal movements as elicited in single, two-place and three-place, imitative articulation tasks, by firstly *calculating diadochokinetic rate (DDR)* on these tasks, and secondly, by applying a comprehensive *rating scale* designed for assessing performance on these tasks (perceptual analysis).

The description and discussion of the results for this sub-aim will be divided into two parts. Firstly; various normative *diadochokinetic rate (DDR)-data* will be presented, described and discussed. This will be followed by a joint description and discussion of the perceptual (qualitative) analysis of *overall* S-DDK-performance, based on the application of the compiled *Rating Scale for the Evaluation of Speech Diadochokinesis* (Table 3.11).

Results in both sections of this sub-aim refer to six types of S-DDK. These are *velar* diadochokinesis (DDK)-results (repetitions of [dənə]), *glottal* DDK (repetitions of [pəbə]), *tongue* DDK (repetitions of [tə] and [kə]), *lip DDK* (repetitions of [pə]), *combined DDK in two-place articulation syllable strings*

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(repetitions of [pəkə], [təkə], [kəpə] and [kətə]), and *combined DDK in three-place articulation syllable strings* (repetitions of [pətəkə], [kətəpə] and [təpəkə]).

4.4.1. DESCRIPTION AND DISCUSSION OF DIADOCHOKINETIC RATE (DDR) RESULTS

Diadochokinetic rate (DDR)-data are presented in Tables 4.5, 4.6, 4.7 and 4.8. Since this study aimed to collect specific normative information regarding diadochokinetic rates, all of the following information were included in these tables in order make the data widely applicable for reference and assessment purposes:

-the ***range*** of repetitions of the target word produced in a *five-second time-period* (note that the word 'range' is not used here as a statistical term, but merely indicates the minimum and maximum number of repetitions produced in the five-second time-period)
-the ***mean*** number of repetitions produced in the five-second time-period
-the mean ***percentage correct score*** (PC-score), which indicates how many of the repetitions were produced with complete accuracy
-the ***diadochokinetic rate*** (DDR), which represents the number of repetitions produced per second (rep/sec) and makes the data comparable to norms

In these tables data are reported for *each specific age group*, namely *four*-year-olds (n=3), *five*-year-olds (n=5) and *six*-year-olds (n=2). However, these age-specific group data are merely reported for completeness and possible future comparison of normative data and should be regarded as preliminary due to the small number of subjects per age group it is based on. In addition, data for the *subjects as a group* (n=10) are also reported, which thus represents DDR-data for normal children in the age range 4;0 to 6;7 years.

It is emphasized that the data for the ten *subjects as a group* can clinically speaking be considered to be of higher application value than the *specific* age group data because of several aspects. Firstly, the specific age group data only

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represent very few children of each age, while the data for the subjects as a group represent ten children. Secondly, data of the subjects as a group provide a *range* of expected DDR's which may be more appropriate for normative assessment purposes. It is widely reported in both adult and child studies of S-DDK that large inter-subject and intra-subject variability can occur (Kent,1997). In a clinical setting for example (e.g. assessment of DSD), it may thus be more appropriate to determine whether a child displays DDR-data outside the *normal range* reported for 4;0 to 6;7 year-old normal children in this study, than to compare the child's performance to the norms for his/her specific age group or mean DDR's. The *standard deviation* from the mean for the subjects as a group is thus also reported in the data for reference purposes. As a result of all these factors, the description and discussion of diadochokinetic rate results will mainly focus on the DDR-data of the *subjects as a group (n=10).*

Combined description and discussion of the DDR-results for all the material presented in Tables 4.5 to 4.8 will take place with reference to existing DDR-norms, individual or specific age group trends in performance and data for the different material (i.e. different S-DDK tasks).

TABLE 4.5: DIADOCHOKINETIC RATE DATA FOR [tə], [pə] AND [kə]

Age Range	[tə]			[pə]			[kə]		
	Range	Mean	Mean PC	Range	Mean	Mean PC	Range	Mean	Mean PC
4;0 to 4;8 years	16-18	17	100	15-18	16	100	17-18	17	96
DDR (rep/sec)	3.4			3.2			3.4		
5;0 to 5;6 years	15-25	20	99	16-24	20	100	14-26	19	98
DDR (rep/sec)	4			4			3.8		
6;1 to 6;7 years	14-22	18	100	16-22	19	100	18-20	19	100
DDR (rep/sec)	3.6			3.8			3.8		
4;0 to 6;7 years	14-25	19	97	15-24	19	100	14-26	19	98
DDR (rep/sec)	**2.8 - 5 Mean: 3.8** (STDEV=3.6)			**3 - 4.8 Mean: 3.8** (STDEV=3.1)			**2.8 - 5.2 Mean: 3.8** (STDEV=3.5)		

<u>ABBREVIATIONS</u>: STDEV=Standard deviation Rep/sec=Number of repetitions per second PC=Percentage correct score DDR=Diadochokinetic rate (reported in repetitions per second)

TABLE 4.6: DIADOCKINETIC RATE DATA FOR [pəbə] AND [dənə]

Age Range	[pəbə]			[dənə]		
	Range	Mean	Mean PC	Range	Mean	Mean PC
4;0 to 4;8 years	6-10	8	27	9	9	100
DDR (rep/sec)	1.6			1.8		
5;0 to 5;6 years	8-12	10	24	10-12	11	98
DDR (rep/sec)	2			2.2		
6;1 to 6;7 years	5-7	6	86	8-10	9	85
DDR (rep/sec)	1.2			1.8		
4;0 to 6;7 years	5-12	9	37	8-12	10	96
DDR (rep/sec)	**1 - 2.4 Mean: 1.8** (STDEV=2.3)			**1.6 – 2.4 Mean: 2** (STDEV=1.3)		
DDR based on accurate productions only (S4 and S10)	Distribution: 5-8 Mean: 6.5 DDR: **1 to 1.6**					

<u>ABBREVIATIONS</u>: STDEV=Standard deviation Rep/sec=Number of repetitions per second PC=Percentage correct score DDR=Diadochokinetic rate (reported in repetitions per second)

TABLE 4.7: DIADOCHOKINETIC RATE DATA FOR [pəkə], [təkə], [kəpə] AND [kətə]

Age Range	[pəkə]			[təkə]		
	Range	Mean	Mean PC	Range	Mean	Mean PC
4;0 to 4;8 years	8-10	9	100	7-9	8	92
DDR (rep/sec)	1.8			1.6		
5;0 to 5;6 years	9-14	11	88	9-13	10	98
DDR (rep/sec)	2.2			2		
6;1 to 6;7 years	10-11	11	100	11	11	100
DDR (rep/sec)	2.2			2.2		
4;0 to 6;7 years	8-14	11	94	7-13	10	97
DDR (rep/sec)	**1.6 - 2.8 Mean: 2.2** (STDEV=1.7)			**1.4 - 2.6 Mean: 2** (STDEV=1.8)		

<u>ABBREVIATIONS</u>: STDEV=Standard deviation Rep/sec=Number of repetitions per second PC=Percentage correct score DDR=Diadochokinetic rate (reported in repetitions per second)

TABLE 4.7 (-CONTINUED): DIADOCHOKINETIC RATE DATA FOR [pəkə], [təkə], [kəpə] AND [kətə]

Age Range	[kəpə]			[kətə]		
	Range	Mean	Mean PC	Range	Mean	Mean PC
4;0 to 4;8 years	5-9	7	67	7-8	7	95
DDR (rep/sec)	1.4			1.4		
5;0 to 5;6 years	10-13	11	100	9-10	10	96
DDR (rep/sec)	2.2			2		
6;1 to 6;7 years	8-9	9	94	8-9	9	100
DDR (rep/sec)	1.8			1.8		
4;0 to 6;7 years	5-13	10	89	7-10	9	96
DDR (rep/sec)	**1 - 2.6** Mean: **2** (STDEV=2.3)			**1.4 - 2** Mean: **1.8** (STDEV=1.2)		

ABBREVIATIONS: STDEV=Standard deviation Rep/sec=Number of repetitions per second PC=Percentage correct score DDR=Diadochokinetic rate (reported in repetitions per second)

TABLE 4.8: DIADOCHOKINETIC RATE DATA FOR [pətəkə],[kətəpə] AND [təpəkə]

Age Range	[pətəkə]			[kətəpə]			[təpəkə]		
	Range	Mean	Mean PC	Range	Mean	Mean PC	Range	Mean	Mean PC
4;0 to 4;8 years	5	5	87	4-5	5	50	4-5	5	60
DDR (rep/sec)	1			1			1		
5;0 to 5;6 years	6-9	7	74	5-7	6	91	3-6	5	75
DDR (rep/sec)	1.4			1.2			1		
6;1 to 6;7 years	6	6	100	4-5	5	68	5-6	6	59
DDR (rep/sec)		1.2			1			1.2	
4;0 to 6;7 years	5-9	6	83	4-7	5	74	4-6	5	67
DDR (rep/sec)	**1 - 1.8** Mean: **1.2** (STDEV=1.3)			**0.8 - 1.4** Mean: **1** (STDEV=0.9)			**0.8 - 1.2** Mean: **1** (STDEV=1.1)		

ABBREVIATIONS: STDEV=Standard deviation Rep/sec=Number of repetitions per second PC=Percentage correct score DDR=Diadochokinetic rate (reported in repetitions per second)

4.4.1.1. Description and discussion of general trends in DDR-data

Results indicated that the fastest DDR's were obtained for [tə], [pə], and [kə], with a DDR-range for the subjects as a group ranging from of 2.8 to 5.2 rep/sec across these words (see Table 4.5). The second fastest DDR's occurred for two-syllable strings ([pəbə], [dənə], [pəkə], [təkə], [kəpə] and [kətə]), with a DDR-range for the subjects as a group ranging from 1 to 2.8 rep/sec across these words (see Tables 4.6 and 4.7). The slowest DDR's occurred with three-syllable strings [pətəkə], [kətəpə] and [təpəkə]), with DDR's for the subjects as a group ranging from 1 to 1.8 rep/sec (see Table 4.8). An overview of the data in Tables 4.5 to 4.8 thus indicated that DDR's decreased as the syllable length of the material increased, which is in agreement with previously reported data (Fletcher,1972;

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Yoss & Darley,1974; Ludwig,1983; Robbins & Klee,1987; Kent,1997). (Note that the percentage correct score data will be discussed in the following section on perceptual results).

Table 4.9 provides a comparison of existing DDR-norms for English on similar material, with the norms obtained in this study. (It should be noted that the present study is unique in the sense that it aimed to collect DDR's about a variety of S-DDK material). Since it represents normative information of a wider variety of S-DDK-tasks than those reported in other studies, only limited discussion of some material is possible).

TABLE 4.9: DDR'S OBTAINED BY AGE GROUPS IN THIS STUDY COMPARED WITH PREVIOUSLY REPORTED MEAN DDR'S (MEASURED IN REPETITIONS PER SECOND)

TARGET (*Afrikaans and English*)	REPORTED DDR's (measured in repetitions per second)							
	Fletcher (1972) (English)	**Yoss and Darley (1974) (English)**	**Bernstein (1980) (Afrikaans)**	**Ludwig (1983) (English)**	**Robbins and Klee (1987) (English)**	**Irwin and Becklund (1953) (English)**	**Kent (1997) (Based on mean data reported in literature for English)**	**Present Study (Afrikaans)**
[pə] / [pʌ]	4yrs: - 5yrs: - 6yrs: 4.2	4yrs: - 5yrs: 4.2 6yrs: 4.5		4yrs: 3.6 5yrs: 4.2 6yrs: -	4yrs: 4.9 5yrs: 4.8 6yrs: 5.4	4yrs: - 5yrs: - 6yrs: 2.5 - 4.7 (M: 3.6)	4yrs: 4.7 5yrs: 4.9 6yrs: 5.3	4yrs: 3.2 5yrs: 4 6yrs: 3.8
[tə] / [tʌ]	4yrs: - 5yrs: - 6yrs: 4.1	4yrs: - 5yrs: 4.2 6yrs: 4.5		4yrs: 4.3 5yrs: 4.3 6yrs: -	4yrs: 4.8 5yrs: 4.8 6yrs: 5.3	4yrs: - 5yrs: - 6yrs: 2.4 - 4.6 (M: 3.4)	4yrs: 4.7 5yrs: 4.9 6yrs: 5.3	4yrs: 3.4 5yrs: 4 6yrs: 3.6
[kə] / [kʌ]	4yrs: - 5yrs: - 6yrs: 3.6	4yrs: - 5yrs: 3.9 6yrs: 4.3		4yrs: 3.9 5yrs: 3.9 6yrs: -	4yrs: 4.6 5yrs: 4.6 6yrs: 4.9	4yrs: - 5yrs: - 6yrs: 2.3 - 4.3 (M: 3.2)	4yrs: 4.3 5yrs: 4.7 6yrs: 4.8	4yrs: 3.4 5yrs: 3.8 6yrs: 3.8
[pətəkə] / [pʌtʌkʌ]	4yrs: - 5yrs: - 6yrs: 1	4yrs: - 5yrs: 3.4 6yrs: 3.8	4yrs: - 5yrs: 1.3 6yrs: -	4yrs: 1 5yrs: 0.9 6yrs: -				4yrs: 1 5yrs: 1.4 6yrs: 1.2

NOTES: (1): Norms from the different studies were converted to repetitions per second in order to make data comparable irrespective of whether the 'count-by-time' or 'time-by-count' method of assessment was used. (2) This study also reported data for additional material (see description and discussion of results) ABBREVIATIONS: M=Mean yrs=years

When the data in Table 4.9 are reviewed it can be seen that the range of DDR-values obtained by the age groups in this study for [tə], [pə], [kə] (i.e. ranging overall from 3.2 to 4 rep/sec), fell *within the range* of DDR's previously reported

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for these syllables (i.e. ranging overall from 2.4 to 5.4 rep/sec). The range of DDR-values obtained by the subjects in this study for [pətəkə] (i.e. ranging overall from 1 to 1.4 rep/sec) also fell *within the range* of DDR's previously reported for these syllables (i.e. ranging overall from 0.9 to 3.8 rep/sec).

However, the ***mean*** DDR's for the age groups on [tə], [pə], and [kə] for example, agreed well with those norms reported by Ludwig (1983) and Irwin and Buckland (1953), but were slightly *slower* than the data of Robbins and Klee (1987) and Kent (1997). DDR's for [pətəkə] agreed with norms reported by Ludwig (1983), Bernstein (1980) and Fletcher (1972) but were again *slower* than the norms reported for normal control subjects by Yoss and Darley (1974). No reported norms could be found for the rest of the material used in this study, but the DDR's displayed by the subjects for [dənə], [pəbə], [pəkə], [təkə], [kəpə] and [kətə] also fell within in the reported distribution in Table 4.9. DDR's for two-place syllable strings were slightly slower than the DDR's for CV-syllables, yet faster than the DDR's for three-place syllable strings. This is in agreement with the general expectation that shorter syllable strings will lead to faster DDR's than longer syllable strings (Baken,1987).

4.4.1.2. Discussion of instances of slower DDR's found in this study than those reported in some other studies

Some explanations can be offered for the sometimes slower DDR's displayed by subjects in this study than those reported in some other studies (e.g. Robbins & Klee,1987). Firstly, it has to be mentioned that slightly different vowels are applicable for English and Afrikaans material (i.e. [ə] vs. [ʌ]), which could have contributed to the slightly slower mean DDR's in this study. It was also noticed that the subjects in the present study articulated the vowels in each CV-syllable distinctly, usually emphasizing the vowel in the first syllable, which could also have slowed their DDR's. Further, this study elicited the DDR-samples in a game (play elicitation mode), which succeeded in keeping the subjects interested in the tasks and encouraged co-operation especially from younger subjects, but could have interfered with the rate of execution. Although unlikely, since the examiner

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manipulated the toys involved, subjects still might have concentrated more on the actions of the toys than on their productions.

In addition, children in this study were encouraged to say the target words fast, but were urged not to go "too fast". Robbins and Klee (1987) for example, instructed their subjects to repeat the material as "quickly as possible" during a three-second-period. In the present study it was also noticed that children's fastest productions occurred very early in the eight-second-period of elicitation (DDR's were determined over the first five seconds), where after they maintained a steady rate of production. It can be speculated that if the DDR's in this study were determined over a period of three seconds only, faster mean DDR's would possibly have been obtained. Irwin and Becklund (1953) for example, also determined their DDR's over a five-second period and showed DDR's closer to those reported in this study (see Table 4.9).

Subsequently, when all these differences are considered, it should be emphasized that the normative information obtained in this study are most applicable for Afrikaans-speaking children, and should only be used in diagnostic settings where the DDR's were elicited exactly as described in this study (i.e. with a similar elicitation mode and instructions). The examiner would like to point out that this method of eliciting S-DDK-data is recommended for clinical use with children in this age range, due to its simplicity and the good amount of subject-co-operation it elicited.

4.4.1.3. <u>Description and discussion of individual and specific age group data</u>

Specific age group results indicated a general tendency for the four-year-old subjects to show slightly slower DDR's than the five and six-year-olds, although these differences were sometimes very small (See Tables 4.5 to 4.8). Occasionally a four-year-old also displayed slightly faster DDR's than some six and five-year-olds. The five-year-olds as a group generally displayed the fastest DDR's, but this was mostly caused by the very fast DDR's displayed by S7. A

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review of the individual data indicated that five and six year-olds performed quite similarly (see Tables 4.10 to 4.13 for individual DDR-data).

The general consensus in literature regarding DDR-information is that younger children can be expected to show slower DDR's than older children (e.g. Baken,1987). However, variability in performance is also frequently cited and a review of the reported norms in Table 4.9 indicated very small differences between the DDR's of four, five and six-year-olds. From the distribution of performance reported by Irwin and Becklund (1953), it can be seen that a wide range of DDR's is possible, even for six-year-olds. Subjects in this study also displayed inter-subject variability in the number of syllables produced in the five-second time-period.

As previously explained, specific age group results should be considered very tentatively in the light of the small number of subjects used in this study. Larger subject groups in subsequent studies will throw more light on these identified, possibly age-related performance trends in Afrikaans children's speech diadochokinesis. Until more information has been obtained, it is again recommended that the *range* (lowest and highest DDR's, means etc.) obtained by the ten *subjects as a group* for particular material is used for evaluation purposes and *not specific age group data.*

4.4.1.4. Description and discussion of DDR's for material of the same structure

When the DDR-distributions for the different material in Tables 4.2 to 4.8 are considered for the subjects as a group, it can be seen that results for tongue and lip DDK in *CV-syllables* were more or less the same for all three target words (same means for [pə], [kə], and [tə]). Slightly slower DDR's were obtained for glottal (i.e. [pəbə]) than for velar DDK-tasks (i.e.[dənə]) (see Table 4.6). In addition, subjects also displayed very low PC-scores on the glottal DDK-task, further indicating that glottal DDK might be more difficult to accomplish than velar DDK (this will discussed more in depth in the next section).

The DDR's for the subjects as a group for <u>two-place</u> tongue and lip DDK-tasks (Table 4.7) indicated slightly faster DDR's for [pəkə] and [təkə] (front-to-back DDK) than for [kəpə] and [kətə] (back-to-front DDK). Results for <u>three-place</u> lip and tongue DDK-tasks indicated the fastest DDR's for front-middle-back DDK (i.e.[pətəkə]), second fastest DDR's for back-middle-front DDK (i.e.[kətəpə]) and slightly slower DDR's for mixed DDK (middle-front-back i.e. [təpəkə]).

However, DDR-differences between material of the same category were very small and only limited interpretations can be made regarding DDR's in different contexts from this study. Although these results do indicate some interesting trends in performance that may be explored in future studies, more extensive research is needed regarding the relationship between DDR's and context before conclusions can be reached.

4.4.2. DESCRIPTION AND DISCUSSION OF PERCEPTUAL ANALYSIS RESULTS FOR S-DDK

Performance was rated in terms of four categories on the compiled *Rating Scale for the Evaluation of Speech Diadochokinesis* (Table 3.11) named *I. Continuity*, *II. Associated Movements*, *III. Accuracy* and *IV. Sound Structure*. The results will be discussed in terms of the subjects' performance on these categories for the different material. In the following discussion, material corresponds with the material outlined in Table 3.5 and the *Test/Recording/Rating Sheet* compiled for sub-aim three (Appendix C). Roman numerals (e.g. II.) represent <u>*categories*</u> on the rating scale (Table 3.11) while lower case letters (e.g. b.) represent <u>*ratings*</u> in each category of the scale.

The overall, perceptual S-DDK data are summarized in Tables 4.10, 4.11, 4.12 and 4.13. In all categories an (a)-rating (indicated by an asterisk in the a-rating column) indicated that *no problems* were displayed for that category and that the subject thus produced *all* of the repetitions produced in the five-second time-period without any problems in that particular category. Numerical entries in columns other than (a) represent the number of times a particular error rating

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occurred across all of a subjects' repetitions in the five second time-period, except for continuity ratings (Category I.) which just consisted of an overall rating, and was thus only indicated by an asterisk in the applicable rating column. It is again emphasized that it was possible for a subject to score more than one error rating per repetition on categories III. (*Accuracy*) and IV. (*Sound Structure*). Multiple error ratings were also possible across categories for the same repetition (see Chapter 3 for clarification). In all the tables PC-scores (percentage correct) refer to the percentage of repetitions a subject produced with perfect accuracy, sound structure, continuity and without any associated movements. *Group PC-scores* will be discussed based on the data previously presented in Tables 4.5 to 4.8.

The perceptual S-DDK results will be described and discussed in terms of tongue and lip DDK in CV-syllables (i.e. [pə], [tə] and [kə]), followed by data for glottal DDK (i.e. [pəbə]), two-place lip, tongue and velar DDK in CVCV-syllables (i.e.[pəkə], [təkə], [kəpə] and [kətə]) and finally results for three-place DDK in CVCVCV-syllables (i.e. [pətəkə], [kətəpə] and [təpəkə]).

4.4.2.1. <u>Description and discussion of perceptual S-DDK-results for [pə], [tə] and [kə]</u>

The following results were obtained for tongue and lip DDK in CV-syllables [pə], [tə] and [kə] with regard to error ratings and PC-scores. Data from Table 4.5 indicated that the subjects as a group obtained a PC-score of 100 for [pə], 98 for [kə] and 97 for [tə], while data in Table 4.10 showed that error ratings (i.e. ratings other than (a) on the rating scale) were only displayed for [kə] and [tə].

Individual data in Table 4.10 indicated that only S7 and S1 scored PC-scores lower than 100 for these syllables. However, S7 also displayed the most repetitions in five seconds for all three CV-syllables, implying that too fast an execution rate might have resulted in his accuracy errors.

TABLE 4.10: SPEECH DIADOCHOKINESIS PERCEPTUAL RESULTS FOR [pə], [tə] AND [kə]

SUBJECT	PC-score	Nr. of R/5/s	I. Conti-Nuity	II. Associated Move-ments	III. Accuracy			IV. Sound Structure		General consistency of overall error pattern
			a.*	a.*	a.*	d.*	f.*	a.*	d.*	
[pə]										
S1	100	*18*	*	*	*			*		
S2	100	*15*	*	*	*			*		
S3	100	*16*	*	*	*			*		
S4	100	*18*	*	*	*			*		
S5	100	*16*	*	*	*			*		
S6	100	*22*	*	*	*			*		
S7	100	*24*	*	*	*			*		
S8	100	*20*	*	*	*			*		
S9	100	*16*	*	*	*			*		
S10	100	*22*	*	*	*			*		
[tə]										
S1	100	*17*	*	*	*			*		
S2	100	*16*	*	*	*			*		
S3	100	*18*	*	*	*			*		
S4	100	*18*	*	*	*			*		
S5	100	*15*	*	*	*			*		
S6	100	*22*	*	*	*			*		
S7	88	*25*	*	*		3		*	3	Consistent
S8	100	*21*	*	*	*			*		
S9	100	*14*	*	*	*			*		
S10	100	*22*	*	*	*			*		
[kə]										
S1	88	*17*	*	*			2	*		Consistent
S2	100	*17*	*	*	*			*		
S3	100	*18*	*	*	*			*		
S4	100	*15*	*	*	*			*		
S5	100	*14*	*	*	*			*		
S6	100	*22*	*	*	*			*		
S7	92	*26*	*	*			2	*		Consistent
S8	100	*20*	*	*	*			*		
S9	100	*18*	*	*	*			*		
S10	100	*20*	*	*	*			*		

**Please refer to the Rating Scale for Speech Diadochokinesis (TABLE 3.11) for definitions of these abbreviations*

** Nr. of r/5/s =Number of repetitions produced in 5 seconds*

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S1 scored two (f)-ratings (i.e. *Mild phonetic inaccuracy of vowel*) on *Accuracy* (i.e. Category III.), due to slight distortion of [kə] to almost [kæ] on two repetitions, which could also have been caused by fast execution for that particular target. In summary, the subjects thus displayed very few errors with CV-syllable S-DDK-tasks.

4.4.2.2. <u>Description and discussion of perceptual S-DDK-results for [pəbə]</u>

Results in Table 4.6 indicated that with all S-DDK-material considered, the subjects as a group obtained the <u>lowest</u> PC-score (i.e. 37) for this two-place, glottal (i.e. [pəbə]) DDK-task. Data in Table 4.11 indicated that only two subjects (i.e. S10 and S4) managed to obtain a PC-score of 100 for this utterance, with two subjects (S7 and S8) even scoring PC-scores of 0. It was noted that both S10 and S4 reduced their execution rate considerably. S4 maintained a rhythmic but slow execution rate (i.e. Category I.(b)-rating), and scored a (b)-rating (i.e. *slow execution but accurate*) on Accuracy (Category III.). S10 *displayed successful self-correction without prompting* (i.e. Category IV.(b)-rating) also leading to a (d)-rating (i.e. *mildly intermittent/a-rhythmic due to self-correction or a syllable addition in the middle of the series*) in Category I. (Continuity), and further a (b)-rating (i.e. *slow execution but accurate*) in Category III. (Accuracy). The low PC-scores for this target were mostly caused by the fact that the majority of subjects produced the target sequence as "[bəbə]" or "[pəpə]", resulting in a *voicing error* (i.e. III.(d)-rating) and *substitution with a sound/syllable in the target utterance-error* (i.e. a IV(c)-rating, see Table 4.11).

The results for [pəbə] may indicate that normal children between 4;0 and 6;7 years find glottal S-DDK more difficult than other S-DDK-tasks in terms of *accuracy*. Production of this sequence requires that the glottis (vocal cords) is opened for the production of voiceless [p] and then closed for voiced [ə], [b] and [ə]. Presumably, some normal children this age still find repetitive execution of these alternating articulatory movements difficult. Even when the subjects were alerted to the fact that they should produce two distinctly different sounds, voicing errors continued to occur.

TABLE 4.11: SPEECH DIADOCHOKINESIS PERCEPTUAL RESULTS FOR [pəbə] AND [dənə]

Subject	PC-score	Nr. of r/5/s	I. Continuity				II. Ass. Movem.	III. Accuracy			IV. Sound Structure							General Consistency Of Overall Error Pattern
			a.*	b.*	c.*	d.*	a.*	a.*	b.*	d.*	a.*	b.*	c.*	g.*	h.*	j.*	k.*	
[pəbə]																		
S1	22	*9*	*				*			8			8			1		Inconsistent
S2	50	*6*		*			*			3			3					Inconsistent
S3	10	*10*	*				*			9			9					Consistent
S4	100	*8*		*			*		*		*							
S5	9	*11*	*				*			10			10					Consistent
S6	11	*9*			*		*			8			8		1			Inconsistent
S7	0	*12*	*				*			12			12					Consistent
S8	0	*11*	*				*			11			11					Inconsistent
S9	71	*7*				*	*			2			2					Consistent
S10	100	*5*				*	*		*			1						
[dənə]																		
S1	100	*9*	*				*	*			*							
S2	100	*9*	*				*	*			*							
S3	100	*9*	*				*	*			*							
S4	100	*11*	*				*	*			*							
S5	90	*10*			*		*	*									1	
S6	100	*12*	*				*	*			*							
S7	100	*12*	*				*	*			*							
S8	100	*10*	*				*	*			*							
S9	100	*8*	*				*	*			*							
S10	70	*10*	*				*	*			*			3	3		3	Consistent

** Nr.r/5/s= Number of repetitions per 5 seconds * Please refer to the Rating Scale for Speech Diadochokinesis (TABLE 3.11) for definitions of these abbreviations*

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S7 for example, who displayed the fastest overall DDR's, did not manage to produce any correct productions of the this target sequence at all (although he did indicate awareness of the auditory difference between [b] and [p]).

It can be argued that auditory discrimination problems could also have contributed to the children's difficulty, since the [p] and [b]-sounds are perceptually very similar. However, in the pre-test elicitation of these targets, all the subjects (except S7, as discussed) could produce two distinct sounds, indicating that the auditory difference was recognized, which reduces this possibility. In addition, it is possible that in the S-DDK-task the subjects concentrated so hard on production of the repetitive movements that they did not pay attention to maintaining the perceptual distinction between the two sounds, or that their perception was distorted due to the fast rate of production. It is not certain whether the subjects were aware of their voicing errors, though, and any suggestions regarding the possible influence of perceptual factors on the data remains hypothetical and in need of further investigation.

It seemed that the children were more likely to manage this target sequence accurately when they reduced the rate of performance significantly (as displayed by S4 and S10, see Table 4.11). For this target utterance it thus may be more appropriate to use these two subjects' data for normative DDR-guidelines (previously discussed), since their results represent accurate productions. This would reduce the group-DDR for [pəbə] in Table 4.6 from 1 to 2.4 rep/sec to 1 to 1.6 rep/sec.

However, it was noted that reductions in performance rate did not result in increased accuracy in every case. (e.g. S2). Results showed that while some children in the study were thus inclined to be more accurate production when they had more time to execute the target utterance, others couldn't accomplish increased accuracy even when they did reduce their execution rate. In addition, results did not indicate this rate reduction to be a trend in general performance across the subject group. Most children did not show any adaptation in execution rate or did not indicate any awareness of inaccurate production. Very individual trends in performance thus occurred, due to possibly a variety of different

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influential factors (e.g. personality aspects such as perseverance, motivation to get the task right, perceptual factors, neurophysiological-maturational factors or other presently yet unknown factors).

However, these findings may indicate that a *reduction in execution rate* (evidenced in a decreased DDR) accompanied by *increased accuracy*, can be regarded as a positive trend in performance. It can be suggested that in such instances the child possibly reduces execution rate to allow more time for successful sensorimotor planning of the utterance, resulting in improved accuracy, sequencing, and continuity. This may further be taken as evidence to suggest that some normal children between the age of 4;0 and 6;7 years may apply a reduction in execution rate as a natural, *compensatory strategy* to accomplish more complex, articulatory movement sequences. Normal adult speakers for example, will also reduce speaking rate when an unfamiliar or long word is to be produced (Van der Merwe, 1997).

These results further led to the conclusion that aspects of both rate (DDR) and accuracy should be considered when children's performances on more difficult S-DDK-tasks are evaluated. However, presently the exact relationship between DDR (rate) and aspects such as accuracy, sequencing, and continuity is unclear, which limits interpretations. Such a relationship can at best be assumed to be complex and certainly is an area in need of more extensive investigation.

4.4.2.3. Description and discussion of perceptual S-DDK-results for [dənə], [pəkə], [təkə], [kətə] and [kəpə]

Data in Table 4.6 showed that the subjects as a group obtained a high PC-score of 96 for two-place velar DDK (i.e. [dənə]), with only two subjects (S5 and S10) scoring any error ratings (see Table 4.11 for details). Results for two-place lip and tongue DDK-tasks also showed PC-scores above 90% for [pəkə], [təkə] and [kətə], with a group PC-score of 89% for [kəpə] (Table 4.7). The latter score was mostly due to a PC-score of 0 obtained by S1 (four-years-old), as can be seen from the results in Table 4.12.

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Data thus showed that the subjects displayed very few error ratings for two-place S-DDK-tasks and that performance for two-place S-DDK-tasks was very similar (except for [pəbə], as discussed in the previous section). Subjects displayed no problems with either *Continuity* (Category I) or with *Associated movements* (Category II). *Accuracy (Category III)* error ratings only occurred for S7 and S8 in the form of (f) error-ratings (i.e *insertion*). The rest of the errors that occurred for these two-place S-DDK tasks were restricted to errors in terms of Sound Structure (Category IV) and ranged from occasional *syllable additions* (i.e. IV-e) and *substitutions* (i.e. IV-c), to *sound insertions* (i.e. IV-f) and *transpositionings* (i.e. IV-j), (see Table 4.12).

As with CV-syllable S-DDK-tasks, it was noticed that some subjects with very fast DDR's (i.e. produced many rep/sec) sometimes showed reduced accuracy, maybe as result of too fast an execution rate. S7 for example, maintained the fastest DDR for [pəkə] (DDR=2.8), but obtained the lowest PC-score (i.e. 57), although he did score a PC-score of 100 for the rest of the two-syllable S-DDK-tasks. In contrast, the youngest subject displayed a DDR of only 1.6 for [pəkə] but obtained a PC-score of 100 (Table 4.12), again suggesting that both accuracy and performance rate (DDR) should be considered in S-DDK-testing. Other subjects again, maintained fast execution rates without any accuracy problems (e.g. S5). Results thus indicated that these normal children were generally capable of accurate production of two-place S-DDK-tasks, although individual trends in performance occurred.

TABLE 4.12: SPEECH DIADOCHOKINESIS PERCEPTUAL RESULTS FOR [pəkə], [təkə], [kəpə] AND [kətə]

Subject	PC-score	Nr. of R/5/s	I. Conti-Nuity		II. Ass. Move-ments	III Accura-cy		IV. Sound Structure					General Consistency of Error Pattern
			a.*	d.*	a.*	a.*	f.*	a.*	c.*	e.*	f.*	j.*	
[pəkə]													
S1	100	*8*	*		*	*		*					
S2	100	*9*	*		*	*		*					
S3	100	*10*	*		*	*		*					
S4	100	*9*	*		*	*		*					
S5	91	*11*	*		*	*				1			
S6	100	*12*	*		*	*		*					
S7	57	*14*	*		*		6	*					Consistent
S8	91	*11*	*		*		1	*					
S9	100	*10*	*		*	*		*					
S10	100	*11*	*		*	*		*					
[təkə]													
S1	75	*8*	*		*	*			1	1			Inconsistent
S2	100	*7*	*		*	*		*					
S3	100	*9*	*		*	*		*					
S4	100	*9*	*		*	*		*					
S5	90	*10*	*		*	*					1		
S6	100	*9*	*		*	*		*					
S7	100	*13*	*		*	*		*					
S8	100	*11*	*		*	*		*					
S9	100	*11*	*		*	*		*					
S10	100	*11*	*		*	*		*					
[kəpə]													
S1	0	*5*	*		*	*				5			Consistent
S2	100	*9*	*		*	*		*					
S3	100	*8*	*		*	*		*					
S4	100	*12*	*		*	*		*					
S5	100	*10*	*		*	*		*					
S6	100	*11*	*		*	*		*					
S7	100	*13*	*		*	*		*					
S8	100	*10*	*		*	*		*					
S9	88	*8*	*		*	*					1		
S10	100	*9*	*		*	*		*					

**Please refer to the Rating Scale for Speech Diadochokinesis (TABLE 3.11) for definitions of these abbreviations*
** Nr. of R/5/s=Number of repetitions produced in 5 seconds*

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TABLE 4.12 (-CONTINUED): SPEECH DIADOCHOKINESIS PERCEPTUAL RESULTS FOR [pəkə], [təkə], [kəpə] AND [kətə]

Subject	PC-score	Nr. of R/5/s	I. Conti-Nuity		II. Ass. Move-ments	III Accura-cy		IV. Sound Structure					General Consistency of Error Pattern
			a.*	d.*	a.*	a.*	f.*	a.*	c.*	e.*	f.*	j.*	
[kətə]													
S1	86	7	*		*	*				1			
S2	100	7	*		*	*		*					
S3	100	8	*		*	*		*					
S4	78	9		*	*	*				1		1	Consistent
S5	100	10	*		*	*		*					
S6	100	10	*		*	*		*					
S7	100	9	*		*	*		*					
S8	100	10	*		*	*		*					
S9	100	8	*		*	*		*					
S10	100	9	*		*	*		*					

***Please refer to the Rating Scale for Speech Diadochokinesis (TABLE 3.11) for definitions of these abbreviations*
** Nr. of R/5/s=Number of repetitions produced in 5 seconds*

4.4.2.4. Description and discussion of perceptual S-DDK-results for [pətəkə], [kətəpə] and [təpəkə]

Results for three-place lip and tongue DDK indicated the highest group PC-score for front-middle-back DDK (i.e.[pətəkə]), second highest for back-middle-front DDK (i.e.[kətəpə]) and slightly lower PC-scores for mixed diadochokinesis (middle-front-back i.e. [təpəkə]) (see Table 4.8) This is exactly the same order as found in the previously discussed DDR-results for this material. The subjects as a group thus displayed the second slowest DDR's and PC-scores for three-place S-DDK-tasks (as discussed before, only data for [pəbə] had lower PC-scores and DDR's).

Investigation of individual data (Table 4.13) indicated that 50% of the subjects (S2, S3, S8, S9, S10) scored no error ratings in any category of the rating scale for [pətəkə], while 40% of the subjects (S3, S4, S5, S8) scored no error ratings in any category of the rating scale for [kətəpə]. Only two subjects (S6 and S9) scored no error ratings in any category of the rating scale for [təpəkə].

TABLE 4.13: SPEECH DIADOCHOKINESIS PERCEPTUAL RESULTS FOR [pətəkə],[kətəpə] AND [təpəkə]

Subject	PC-score	Nr. of R/S/s	I. Continuity				II. Ass. Movem.	III. Accuracy		IV. Sound Structure									General Consistency of Error Pattern
			a.*	b.*	c.*	d.*	a.*	a.*	d.*	a.*	b.*	c.*	d.*	e.*	f.*	g.*	j.*	k.*	
[pətəkə]																			
S1	60	5	*				*	*								1	1		Inconsistent
S2	100	5	*				*	*		*									
S3	100	5	*				*	*		*									
S4	86	7				*	*	*			1								
S5	33	6	*				*	*					4						Inconsistent
S6	89	9			*		*	*							1				
S7	63	8				*	*	*						4			1		Inconsistent
S8	100	6	*				*	*		*									
S9	100	6	*				*	*		*									
S10	100	6	*				*	*		*									
[kətəpə]																			
S1	0	5	*				*	*				5							Consistent
S2	50	4		*			*	*									2		Consistent
S3	100	5	*				*	*		*									
S4	100	6	*				*	*		*									
S5	100	5	*				*	*		*									
S6	83	6			*		*	*										1	
S7	71	7				*	*	*								1	1		Inconsistent
S8	100	6	*				*	*		*									
S9	60	5				*	*		1		1		1		1				
S10	75	4	*				*	*				1							

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TABLE 4.13 (-CONTINUED): SPEECH DIADOCHOKINESIS PERCEPTUAL RESULTS FOR [pətəkə], [kətəpə] AND [təpəkə]

Subject	PC score	Nr. of R/5/s	I. Continuity				II. Ass. Movem.	III. Accuracy		IV. Sound Structure									General Consistency of Error Pattern
			a.*	b.*	c.*	d.*	a.*	a.*	d.*	a.*	b.*	c.*	d.*	e.*	f.*	g.*	j.*	k.*	
[təpəkə]																			
S1	80	5	*				*	*				1							
S2	0	4		*			*	*									4		Consistent
S3	100	5		*			*	*		*									
S4	83	6	*				*	*						1					
S5	100	3		*			*	*		*									
S6	100	6	*				*	*		*									
S7	25	4				*	*	*						1				2	Inconsistent
S8	67	6	*				*	*				1				1			Inconsistent
S9	100	5	*				*	*		*									
S10	17	6				*	*	*				4			1		1	1	Inconsistent

**Please refer to the Rating Scale for Speech Diadochokinesis (TABLE 3.11) for definitions of these abbreviations*
** Nr. of R/5/s= Number of repetitions produced in 5 seconds*

The type of perceptual errors that occurred can also be seen in Table 4.13. Category IV errors occurred the most (i.e. errors with *sound structure*) but the type of ratings differed among subjects. Not one error rating (i.e. ratings other than 'a' dominated the scoring, indicating very individual trends in error patterns. In summary, the results of three-place articulation possibly indicated that S-DDK in back-middle-front and mixed (middle-front-back) place-of-articulation sequences may be 'more difficult' than front-middle-back S-DDK for normal children in this age range.

4.4.2.5. Conclusive discussion of perceptual S-DDK-results

Perceptual analysis of the S-DDK-data led to the conclusion that normal children aged 4;0 to 6;7 years displayed very few errors for CV-syllable and most CVCV-syllable S-DDK-tasks, and displayed no problems with associated movements in any of the S-DDK-tasks.(The latter observation is contrary to the findings for non-speech DDK tasks, where associated movements did occur).

However, many of these normal subjects displayed errors in terms *of accuracy, sound structure* and *continuity* for *glottal* and *three-place* S-DDK material, although these errors were few, individual and not severe. It can be hypothesized that glottal and three-place S-DDK tasks may place more demands on sensorimotor speech planning in terms of aspects of accuracy, continuity, and sound structure (sequencing).

Results suggested that some normal children between the age of 4;0 and 6;7 may apply a *reduction in execution* rate as a natural, compensatory strategy to accomplish more complex articulatory movement sequences. Results did not indicate this rate reduction to be a trend in general performance across the subject group though, since most subjects did not show any adaptation in execution rate, or did not indicate any awareness of inaccurate production. Very individual trends in performance thus occurred, due to possibly a variety of influential factors (e.g. personality aspects such as perseverance, motivation to get the task right, perceptual factors, neurophysiological-maturation or other currently unknown aspects).

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Furthermore, results suggested that evaluation of S-DDK in terms of rate of execution (i.e. DDR, thus *quantitative* analysis) may yield limited information about children's overall S-DDK abilities. Rather, additional analysis of S-DDK in terms of *qualitative* aspects such as continuity, accuracy, sound structure (and associated movements) needs to be considered, since it may provide additional insight into symptom patterns. It is proposed that such analyses of S-DDK might be especially valuable in the case of diagnostic populations (e.g. children with DSD), providing more descriptive information in terms of symptom patterns.

The *Rating Scale for the Evaluation of Speech Diadochokinesis* (Table 3.11) compiled for use in this study may be helpful in such clinical analyses. The categories and ratings were found to be useful in describing and rating the behavior displayed by the normal children, providing valuable information about the characteristics of their performance in the different tasks. By applying this rating scale, the traditional assessment of S-DDK can be expanded beyond the mere calculation of diadochokinetic rates (DDR's) to a more in-depth analysis of symptom patterns. The tentative, normative information regarding the nature of S-DDK in children between 4;0 and 6;7 that has been collected in this study, may be used for comparison in assessment of Afrikaans-speaking children with DSD.

4.5. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM FOUR: CLUSTER PRODUCTION

The goal of this sub-aim was to investigate the ability of normal, Afrikaans-speaking children aged 4.0 to 7.0 years to *recall, plan, organize, and combine motor goals consecutively* during imitative productions of two (CC), and three-consonant (CCC) initial and final clusters in *isolation*. (Material can be viewed in Table 3.6 and Appendix D). Results will firstly be described and discussed in terms of percentage correct (PC)-scores displayed by the subjects for initial and final clusters, followed by a description and discussion of the individual error types that occurred.

4.5.1. PERCENTAGE CORRECT (PC)-SCORES FOR INITIAL AND FINAL CLUSTERS

The percentage correct (PC)-scores obtained by the individual subjects for initial cluster production (ICL) and final cluster production (FCL), are presented in Table 4.14. Mean, group standard deviation and total error percentages (EP's) for each cluster group are also reported.

TABLE 4.14: PERCENTAGE CORRECT SCORES FOR CLUSTERS

Subjects		Percentage Correct Scores for Initial Clusters	Percentage Correct Scores for Final Clusters
Subject	Age (years)		
S1	4;0	93	96
S2	4;1	72	67
S3	4;8	100	79
S4	5;0	79	79
S5	5;3	66	96
S6	5;4	90	67
S7	5;4	100	75
S8	5;6	76	79
S9	6;1	86	96
S10	6;7	76	54
Group Mean:		84%	79%
Group Standard Deviation:		11.8	14.1
Total Error Percentage:		16%	21%

It can be seen from the data in Table 4.14 that the subjects as a group obtained a higher PC-score for ICL than for FCL, although individual performance of the subjects did not indicate *consistent* lower PC-scores for FCL. Some subjects obtained higher PC-scores for FCL than for ICL (e.g. S1, S5 and S9). In the case of initial clusters only two subjects (S3 and S7) obtained a PC of 100, while no subjects managed to obtain a PC-score of 100 for final clusters. Results seem to suggest that normal children between 4;0 and 6;7 years can still show some problems with the production of consonant clusters in isolation and that some children may find the planning and sequencing of motor goals for final cluster combinations more complex than for initial clusters. No age-related trends in cluster production were identified, since very individual performance trends occurred.

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4.5.2. ERROR PERCENTAGES AND ERROR TYPES FOR INITIAL CLUSTERS (ICL)

The subjects as a group showed an error percentage (EP) of 16% for ICL (see Table 4.14), indicating that normal children in this age range can still experience some difficulty with initial cluster production in isolation. Errors that occurred for initial clusters are summarized in Table 4.15, in terms of error types and frequency of occurrence for the subjects as a group.

TABLE 4.15: ERROR TYPES THAT OCCURRED FOR INITIAL CLUSTERS (CC-/CCC-)

ERROR TYPE	INITIAL CLUSTERS IN WHICH THE ERROR TYPE OCCURRED	NUMBER OF SUBJECTS WHO DISPLAYED THIS ERROR TYPE
INSERTION OF SCHWA VOWEL e.g. [fən]	[fn]	7
	[xl]	5
	[kn]	4
	[vr]	3
	[xr]	3
	[bl]	3
	[sl]	2
	[fl]	2
	[kl]	2
	[spl]	2
	[fr]	2
	[pl]	1
	[spr]	1
		Total: 37 (79%)
OTHER ERRORS:	[sn] produced as: [zn]= voicing/substitution [s-nə]=consonant lengthening/vowel addition [sp] produced as: [spə]= vowel addition [spl] produced as: [spi:l]= vowel insertion [xr] produced with voiceless [r]=voicing error [sm] produced as: [sm^h]/[n^h]=nasal distortion [smə]=vowel addition [smən]=syllable addition [spr] produced with voiceless [r]=voicing error [swə] produced with [s]-distortion	
		Total: 10 (21%)

A review of individual results and error patterns in Table 4.15 indicated that 79% of errors with initial clusters were the result of an insertion of the *schwa-vowel* between the first and second elements of CC-clusters, or between the second and third elements of CCC-clusters. The other 21% of errors were of a mixed type. Only 31% of the initial cluster material did not show any errors (i.e. [st/sk/kr/pr/tr/br/dr/skr/ and str]).

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4.5.3. ERROR PERCENTAGES AND ERROR TYPES FOR FINAL CLUSTERS (FCL)

The subjects as a group showed an error percentage of 21% for FCL (see Table 4.14), indicating that normal children in this age range can still experience some difficulty with final cluster production in isolation. Errors that occurred for FCL clusters are summarized in Table 4.16, in terms of error types and frequency of occurrence for the subjects as a group.

TABLE 4.16: ERROR TYPES THAT OCCURRED FOR FINAL CLUSTERS (-CC/-CCC)

ERROR TYPE	FINAL CLUSTERS IN WHICH THE ERROR TYPE OCCURRED	NUMBER OF SUBJECTS WHO DISPLAYED THIS ERROR TYPE
INSERTION OF SCHWA VOWEL e.g. [rəf]	[rf]	4
	[rx]	3
	[rs]	3
	[rf]	3
	[xs]	2
	[rp]	2
	[lp]	1
	[lf]	1
	[lx]	1
	[lt]	1
	[ls]	1
	[rts]	1
		Total: 23 (45%)
ADDITION OF [ɦə] IN FRONT OF THE CLUSTER e.g. [ɦəlk]	[lk]	6
	[lx]	4
	[lt]	3
	[ls]	3
	[lf]	2
	[ŋks]	2
	[ŋk]	1
	[lp]	1
	[nt]	1
	[ns]	1
		Total: 24 (47%)
OTHER ERRORS:	[rf] produced with voiceless [r] [ks] produced as: [k-/st/ts]= sound deletion and substitutions [ns] produced as [nts]= sound insertion [nts] produced as [ŋks]: sound substitutions	
		Total: 4 (8%)

A review of individual results and error patterns in Table 4.16 indicated that 47% of these errors were due to an addition of syllable [ɦə] in front of the cluster.

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45% of the errors were the result of an insertion of the schwa-vowel between the first and second elements of CC-clusters or between the second and third elements of CCC-clusters, while the other 8% of errors were of a mixed type. Only 29% of the final cluster material did not show any errors (i.e. [ləm/mp/ts/ps/rəm/rt/rk]).

4.5.4. DISCUSSION OF RESULTS FOR INITIAL AND FINAL CLUSTERS

The tendency for the subjects to insert a *schwa-vowel* between elements of a cluster (epenthesis), or to insert syllable [ɦə] in front of final clusters can be regarded as way of *simplifying the production* of the cluster in isolation (Khan,1985; Ohde & Sharf,1992). It can be suggested that the insertion of the schwa-vowel or syllables may allow more time for articulatory transitioning and sequencing of motor goals from one consonant to another. Hawkins (1984) stated that epenthesis implies a lack of coarticulation between the elements of a cluster. In English it has been found from phonetic observation that the closure for the first consonant in a cluster is generally not released until after the closure for the second is formed (Byrd & Tan,1996), further indicating that epenthesis may assist in the coordination of articulatory gestures.

Gilbert and Purves (1977) referred to the insertion of a schwa-vowel between clusters in real words as a splitting process and explained it as an attempt to overcome the demands of a time-dominant system. They argued that the child's timing control may not be developed enough to enable him/her to produce the required segments within the limited time allowed and consequently, "...the segmentation of clustered features is exaggerated in the split clusters, allowing target articulation of consonants to be achieved." (Gilbert & Purves,1977:431). From such a viewpoint schwa-vowel insertion may thus be regarded as a compensatory way of handling higher articulatory demands.

It is interesting to note that schwa-epenthesis is not regarded by some authors as being part of the four stages children are said to proceed through as they learn to produce clusters in real words i.e. 1) the entire cluster is omitted, 2) one of the consonants is omitted, 3) the previously deleted consonant is replaced by another, 4) the correct cluster is produced (Greenlee in Ohde & Sharf,1992). Other authors such as Shriberg and Kwiatkowski (1980) again, stated that vowel insertion occurs during stage three of cluster development, or at about two and a half years of age when it will alternate with correct articulation of the cluster.

Another explanation for the high occurrence of schwa-vowel insertion in initial and final clusters and the addition of syllable [fiə] to final clusters, is that it might have been the result of *linguistically-related* or *syllable influences*. As noted in the method (Chapter 3), some subjects' reactions indicated that they perceived the targets as 'odd-sounding', in spite of preparation by the examiner. It should be considered that some subjects found this unfamiliar productions (i.e. devoid of meaning) strange, and that they might have attempted to produce it more familiarly (i.e. more syllable or word-like) by adding a schwa-vowel or [fiə]-syllable. However, this is a mere hypothesis and extensive research is needed before any conclusions can be reached.

As described in Chapter 3, the clusters in this study were elicited in isolation and not in real, meaningful words. It may be argued that a short three-consonant sequence might be less complex to produce than a longer, real word, since less motor goals are involved. Yet, it is also possible that this isolated cluster context, which is devoid of meaning, may give a *clearer* indication of sensorimotor aspects of speech control, since it focuses on the consecutive articulation of two or three sounds *without* direct linguistic influences (as those present in real, meaningful words). In the sensorimotor speech planning phase of speech production hypothesized by Van der Merwe (1997), core motor plan recall of invariant motor plans for these sounds thus have to take place, followed by aspects such as planning of consecutive articulator-specific motor goals, sequencing and inter-articulator synchronization. Some subjects thus showed difficulty in planning and sequence motor goals for some clusters in isolation.

Yet, although not part of the aims of this study, informal review of the subjects' *spontaneous speech sample* (which was used for the next aim), showed that all

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the subjects produced a variety of consonant clusters with 100% accuracy and without any vowel epenthesis in words with clusters, in spite of difficulty with producing the same clusters in isolation. It is unlikely that factors such as imitative vs. spontaneous mode of elicitation could have contributed to the results since Bond and Korte (1983:b) for example found no differences between initial clusters in words produced in imitative vs. spontaneous speech condition.

From the results it thus appeared as if these normal children's *phonetic production repertoire for isolated clusters* differed from their ability to produce the same clusters in *meaningful, spontaneous* speech. Results suggested that even if normal children between 4;0 and 6;7 years are capable of producing clusters accurately in spontaneous speech, some may find it difficult to produce the same clusters in isolation. Results lead to the tentative suggestion that for some normal children, greater demands may be placed on sensorimotor speech control by the cluster-in-isolation context, but it is unclear why this might be the case. This observation is in need of much more future investigation before any conclusions can be made, since the two contexts were not statistically compared. To the knowledge of the examiner no research exists regarding normal children's production of clusters in isolation vs. cluster production in words.

It was very difficult to identify any patterns in cluster errors in terms of place and manner of production or to explain occurring problems. Results also indicated very individual production patterns between subjects. Initial cluster [fn],[xl] and [kn] showed the most errors. All three these clusters involved the progression from voiceless to a voiced sound and two involved a nasal consonant in the second position, possibly indicating some problems with the synchronization of voicing. Final clusters [lk], [lx] and [rf] displayed the highest errors, involving articulatory transitions from a voiced to a voiceless sound and from different places of articulation.

Researchers such as Gilbert and Purves (1977) have found in a segmental duration study of clusters (in Canadian English) that differences between age groups (5, 7, 9, 11-year-olds and adults) in terms of temporal organization of clusters were entirely restricted to clusters with [l] and Hawkins (1973) interpreted [l]-clusters to be more difficult for children than for adults (i.e. British English). Gilbert and Purves (1977) interpreted the lengthening of the [l]-sound in clusters as a further stage of the splitting process, "...an attempt by the child to achieve target articulation of [l] by relaxing the demands of the timing program." (Gilbert & Purves,1977:431). Three of the top six error clusters in the present study also included the [l]-sound. Gilbert and Purves (1977) opposed the view of researchers such as Hawkins (1973) that problems with [l]-clusters is an indication that the [l]-sound is 'more difficult' to produce. According to Gilbert and Purves (1977) the term 'articulatory difficulty' is ill-defined and there is no proof from information about the sequential acquisition of consonants to support the proposal that [l] is more difficult to produce in all contexts or that it is only more difficult to produce in clusters.

In summary, investigation of cluster production in isolation by normal four to six-year-olds raised some interesting questions regarding normal children's ability to plan and sequence speech motor goals for consonants in a *non-linguistic context*. It may be interesting to determine if children with DSD show the same trends in performance displayed by these normal subjects (e.g. the possible compensatory strategy of schwa-insertion etc.), when faced with this possibly 'more demanding' articulatory context. Further investigation regarding various aspects of cluster production (and in different contexts) may lead to interesting observations and deductions regarding sensorimotor speech control. Current suggestions should be regarded tentatively though, awaiting further investigation.

4 .6. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM FIVE: WORD SYLLABLE STRUCTURE

This goal aimed to investigate the ability of normal, Afrikaans-speaking children aged 4;0 to 7;0 years to *recall, plan, combine* and *produce* a variety of *motor*

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goals consecutively for different *word syllable structures, as* manifested in *spontaneous speech* production.

Percentage of occurrence (POO) calculations indicated that 18 different word syllable structure types occurred *at least once* in the spontaneous speech samples of all the children. These structures will be the focus of the description and discussion of results for this sub-aim, since it represents word syllable structures that may be most likely to occur in the speech of normal Afrikaans-speaking children. It thus provides some normative information for comparison with children with DSD. Table 4.17 displays the data for these structures, including the percentage of occurrence (POO) of each word syllable structure in the speech of each subject. The rest of the word syllable structures (that did not occur at least once in the sample of every subject) are displayed in Table 4.18, since it is evidence of normal speaking children's ability to plan and combine a great variety of motor goals consecutively. Figure 4.1 visually displays the top five occurring word syllable structure data for each subject.

TABLE 4.17: SYLLABLE STRUCTURES THAT OCCURRED AT LEAST ONCE IN THE SAMPLES OF ALL TEN SUBJECTS, WITH THEIR PERCENTAGES OF OCCURRENCE (POO's)

Syllable Structure	Total POO	POO for S1	POO for S2	POO for S3	POO For S4	POO for S5	POO for S6	POO for S7	POO for S8	POO for S9	POO for S10
CVC	22.1	23	23.3	22.6	27.1	20.7	19.1	18.9	20.4	27	20.6
CV	15.3	14.3	9.6	15.6	16.2	18.8	17.7	16.4	15.9	8.2	16.1
VC	12.4	13.9	11.6	10.6	8.6	13.6	11.9	11.6	13.6	13.5	15.4
CVV	9.8	7.8	10.6	11.6	9.1	8.7	9.8	9.6	10.8	7.7	12.7
CVCV	4.9	4.3	6.2	4.2	2.5	3.9	5.5	6.9	7	5.4	3.8
CVCVC	3.6	5.1	1.7	3.8	3.2	3.4	3.6	4.7	2.7	2.1	4.1
CCVC	3.6	2.7	2.7	3.2	4.1	5.5	3.2	4.8	1.8	3.0	3.8
V	2.9	3.9	4.1	2.6	2.5	2.5	2.3	3	3.6	4.3	1.1
VCV	2.7	4.5	2.4	2.8	3.6	2.7	1.8	2.7	2.5	2.6	2
CVCC	2.3	1.4	5.8	3.2	1.4	2.1	2.5	0.6	2.9	1.9	3.2
CVVC	2.1	3.7	2.1	1.8	1.6	2.1	2.5	2.1	1.6	0.6	2.3
VCC	1.3	0.6	2.1	1	1.1	0.9	1.2	1.1	1.1	3.2	1.1
CVCCVC	1.2	1.6	2.4	0.6	0.9	1.6	1.5	1.1	0.5	1.1	1.1
CVCCV	0.9	1.6	0.3	1	0.5	0.5	1.3	1	0.5	1.1	1.3
CCVVC	0.9	0.8	1	1.4	0.5	0.9	0.8	1	1.1	0.2	0.9
CCVV	0.6	0.2	0.3	0.4	1.2	1.1	1.3	0.5	0.4	0.6	0.2
VCVC	0.6	0.4	0.7	0.6	0.5	0.5	0.5	0.8	0.5	0.4	0.5
CVVCV	0.5	0.2	0.3	1.2	0.4	0.5	0.7	0.8	0.4	0.6	0.2
TOTAL NUMBER OF STRUCTURES : 18 (11%)											

** POO= Percentage of Occurrence * NOTE: VV refers to diphthongs*

TABLE 4.18: SYLLABLE STRUCTURES THAT DID NOT OCCUR AT LEAST ONCE IN THE SAMPLES OF ALL TEN SUBJECTS AND THEIR TOTAL PERCENTAGES OF OCCURRENCE (POO's)

STRUCTURES	TOTAL % OF OCCUR-RENCE	TOTAL NUMBER OF STRUC-TURES WITH THIS %
VVC	0.6	1
CVCVCVC VCCVC CVCVCC CCVCV VVCV CVCVV CVCVVC CCVCVC	0.4	8
CVCVCV VCCV CCVCC CVVCVC CCVVCV	0.3	5
CCV CVCCVVC CVCCVCCV CVCCCVC C CCVCCVC CVCCVCC CVCCVV CVCCVCCVC VV CCCVC CVVCCV CVCVCCVC CCVCVCVC	0.2	14
CVCCVCVC CVCCVCV CVCVCCV VVCCVC CVVCCCVC VCCCVC CCVCVCV VCCVVC CCVCCV CVCVCVCC CVCVCVCVC CVVCVCVCC CVCCVVCVC VCVCC CVVCVCVC CCVCCCVC VCVCV VCVCVC VCCVCVC VCCVCCVC CVCVVCVC CC CVCCCVCV CVCVCCCV VCVCVCC VVCVCCVC CVCCCVCC	0.1	27
VCCCVV VCCVCCVCC VCCVCVV CVCCCVCCVC CVCCCVVC CVCVCVV CVVCVV CCVVCCVC VVCVC CVCVVCVCCV CVVCVCCVC VVCCVCVC VCCCCVC VCVCVCV CVVCCVC VCVCCVC CCVCCVCVC VCVV CCVCCVCC VCCVCVCC CCVCCVCV CCVCVCC VCVCCVCCV VCCVCCV CVCCVVCV	0.04	25
CCVVCC CVCVCCVVC VCCVCCCVC CVCVCCCVC CVCVCVCVV CCVVCCCCVC CCV CVCCVVCCVC CVCVCCVCC CVCVCVCCVVCV CCVCVCCVC CVCVCCVV CCVCCCVCCVC CCCVCCCVVCV CCVCVCVV CVCCVCCVCCVC CVCVCVVCCV CVCVCVVCV CVCVVCCVC CVVCVCCVCV CVVCVCVCCVC CCVCVCCCVC CVCVCVCCCVC VCVCCVCCVVCVC CVVCCVCCV CVVCVCC CCVCCVVC VCCV CVVCCVVCVC VCCVCVCCVCCCVC VCCVCC CVCCCVCCVCCV CVCCCVV CVCVCVCCCVVC CVCCC CVVCVCVCVC CVCVCCVCVCV CCVVCVVCVCVC CVCCCVCCCCVC CCCVVCV CVCVCVCCVCVCV CVCVCVCCVCVC CCVVCCVCC CVVCCVVC CVCVCCVCV VCCCV VVCCCV CVCCVCVCVC CVCCVCVCVCC CCVCCVCVCCV CVCVCCCVVCVC CCVVCCVCV CCVVCVC CVCCCVVCVCCV CVCCVCCCVC CVCVCVVC VCVCCV CVCCVCCVCC CVCVCVVCCCVCCCVC CVVCCVCV CVCCVCVVCCV VVCCVCCVC CVVCVCCV CCVCCCVCV CVCVCVCVCCV	0.02	65
		145 (89%)

From the data in Tables 4.17 and 4.18 it can be seen that the subjects displayed total of 163 different word syllable structures of which 18 (11%) occurred at least once in the spontaneous speech sample of all the subjects. Data showed that the syllable structures that occurred with the highest frequency were CVC, CV, VC, CVV and CVCV-utterances (from highest to lowest order of occurrence, see Table 4.17). Only 14 syllable structures had a POO of one percent and/or above, indicating that the majority of utterances in these normal Afrikaans-speaking children's speech were limited to these *basic* structures of combination. However, from Table 4.18 it can be seen that the normal children in this age range were able to recall, plan and combine a wide *variety* of motor goals consecutively and were capable to produce words of sometimes great length and complexity. Normal children between the ages of 4;0 and 6;7 years thus seem to be able to plan and program complex sequences of motor goals.

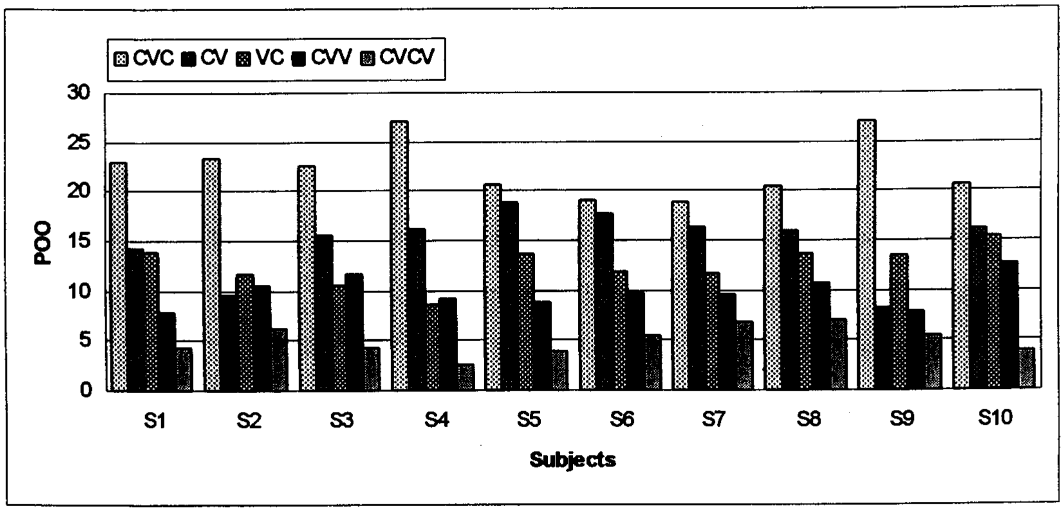

FIGURE 4.1: INDIVIDUAL PERCENTAGES OF OCCURRENCE (POO's) FOR THE TOP FIVE OCCURRING WORD SYLLABLE STRUCTURES

No related studies regarding word syllable structures in normal Afrikaans-speaking children could be identified. However, De Kock (1994) examined the syllable structures of 30 utterances each of four Afrikaans-speaking children between four and six years with suspected developmental apraxia of speech. Although a smaller sample that the present study were used, she found that the subjects only used a total of 18 different syllable structures (as opposed to the 163 in the present study), indicating a limited ability to combine motor plans consecutively and in complex fashion compared to these normal children.

The top five occurring word syllable structures in De Kock's study were CV, CVC, CVCV, VC, V and VCV-utterances, that compare well with those found in the present study (See Table 4.17 and Figure 4.1) Future investigation of the possible differences in the type and frequency of word syllable structures

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displayed by normal children and those with DSD may lead to interesting findings regarding their ability to combine a variety of motor goals consecutively.

4.7. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM SIX: A) FIRST-VOWEL DURATION (FVD) AND B) VARIABILITY OF FVD

The goal of sub-aim six was to investigate acoustically the following aspects of segmental duration in normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, in repeated utterances of the same word:

(a) To obtain *normative* indications of the length of *first-vowel duration (FVD)* in this age range and to determine if any differences exist in the vowel durations of the age groups (four, five, and six-year-olds).

(b) To investigate the nature of *variability* in first-vowel duration in this age range and to determine if any differences in vowel duration variability exist between the age groups (four, five, and six-year-olds).

The description and discussion of the results for this aim will begin with a presentation of the *individual* results obtained by the subjects in terms of *mean FVD* i.e. first-vowel duration in milliseconds (ms) as measured across the five repetitions, *STDEV* (standard deviation) and *CfV* (coefficient of variation) in Table 4.19. The data in Table 4.19 are thus the *individual* results for *both* parts of sub-aim six. Secondly, the specific age-group FVD and FVD-variability data will be presented in Table 4.20, in terms of *minimum and maximum duration, range, mean, STDEV* and the *CfV* for each age group (i.e. four, five, six-year-olds and 4;0 to 6;7 year-olds). The data in Table 4.20 are thus the specific *age group* results for *both* parts of sub-aim six. Tables 4.19 and 4.20 will be followed by a two-part description and discussion of their contents, together with other specific data concerning FVD and variability of FVD.

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TABLE 4.19: INDIVIDUAL FIRST-VOWEL DURATION (FVD) AND FVD-VARIABILITY DATA

TARGET WORD	VALUE	S1 4;0	S2 4;1	S3 4;8	S4 5;0	S5 5;3	S6 5;4	S7 5;4	S8 5;6	S9 6;1	S10 6;7
[pa̲ki]	**Mean FVD (ms)**	87	93	139	123	97	61	60	172	123	112
	STDEV	21.1	5	3.7	21.1	6.9	12.9	9.5	14.9	8.5	9.5
	CfV	0.24	0.05	0.03	0.17	0.07	0.21	0.16	0.09	0.07	0.08
[ba̲ki]	**MeanFVD (ms)**	130	106	127	137	94	118	125	181	129	101
	STDEV	20	7.6	28.1	14.9	9.4	27.1	14.6	7.6	3.2	12.3
	CfV	0.15	0.07	0.22	0.11	0.10	0.23	0.12	0.04	0.02	0.12
[ta̲sə]	**Mean FVD (ms)**	202	143	153	169	118	154	154	193	154	117
	STDEV	18.9	34.9	33.1	12.7	22	13.6	7.7	13	11.9	20.8
	CfV	0.09	0.24	0.22	0.08	0.19	0.09	0.05	0.07	0.08	0.18
[da̲sə]	**Mean FVD (ms)**	175	169	179	184	139	156	149	241	161	152
	STDEV	8.1	12.5	22.9	8.8	13	10.3	15.2	12.6	11	27.7
	CfV	0.05	0.07	0.13	0.05	0.09	0.07	0.10	0.05	0.07	0.18
[tɔ̲pi]	**Mean FVD (ms)**	117	115	117	177	83	108	88	159	122	98
	STDEV	29.4	6.5	15.7	15.6	5.3	11.2	19.1	12.4	12.4	7.5
	CfV	0.25	0.06	0.13	0.09	0.06	0.1	0.22	0.08	0.1	0.08
[dɔ̲pi]	**Mean FVD (ms)**	113	139	129	184	81	105	90	149	123	108
	STDEV	24.2	25.3	19.3	16.1	14.4	15.3	12.3	7.5	15.6	7.1
	CfV	0.22	0.18	0.15	0.09	0.18	0.15	0.14	0.05	0.13	0.07
[tə̲k]	**Mean FVD (ms)**	63	93	101	147	112	67	66	163	103	83
	STDEV	8.3	14.3	10	8.2	15.9	9.4	22	17.9	6.1	7.7
	CfV	0.13	0.15	0.1	0.06	0.14	0.14	0.34	0.11	0.06	0.09
[də̲k]	**Mean FVD (ms)**	124	120	153	234	118	92	69	201	144	108
	STDEV	26.4	10.7	14.9	12.3	20.5	17.9	22.4	16.4	26.7	16.5
	CfV	0.21	0.09	0.1	0.05	0.17	0.19	0.33	0.08	0.18	0.15

ABBREVIATIONS: S=Subject ms=Milliseconds STDEV=Standard deviation CfV=Coefficient of variation

TABLE 4.19 (-CONTINUED): INDIVIDUAL FIRST-VOWEL DURATION (FVD) AND FVD-VARIABILITY DATA

TAR-GET WORD	VALUE	S1 4;0	S2 4;1	S3 4;8	S4 5;0	S5 5;3	S6 5;4	S7 5;4	S8 5;6	S9 6;1	S10 6;7
[ka̠tə]	**Mean FVD (ms)**	109	131	134	113	105	108	118	181	150	113
	STDEV	14.1	22.2	17.5	24	12.9	13.8	12.5	10.8	13.4	14
	CfV	0.13	0.17	0.13	0.21	0.12	0.13	0.11	0.06	0.09	0.12
[fənəx]	**MeanFVD (ms)**	126	114	121	197	133	84	69	216	113	59
	STDEV	14.2	28	23.5	52.3	10.8	10.2	13.6	30.5	13.2	7.6
	CfV	0.11	0.24	0.19	0.27	0.08	0.12	0.2	0.14	0.12	0.13
[knəbəl]	**Mean FVD (ms)**	116	128	130	164	100	116	123	126	103	100
	STDEV	27.9	26.1	25	38	24.3	17.4	14.9	9.7	9.3	21.9
	CfV	0.24	0.2	0.2	0.23	0.24	0.15	0.12	0.08	0.09	0.22
[klɔki]	**Mean FVD (ms)**	88	100	91	149	70	86	68	103	105	88
	STDEV	19.5	10.7	13.5	11.9	11.2	16.4	7.3	6.6	11.7	19.1
	CfV	0.22	0.11	0.15	0.08	0.16	0.19	0.11	0.06	0.11	0.22
[blɔki]	**Mean FVD (ms)**	103	105	104	173	94	85	93	111	118	67
	STDEV	25.4	13.2	19.1	11.4	19.2	10	17.2	9.4	14.9	11.4
	CfV	0.25	0.13	0.18	0.07	0.2	0.12	0.18	0.08	0.13	0.17

ABBREVIATIONS: S=Subject ms=Milliseconds STDEV=Standard deviation CfV=Coefficient of variation

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TABLE 4.20: SPECIFIC AGE GROUP STATISTICS FOR FVD AND VARIABILITY OF FVD

TARGET WORD	MEASURE	AGE GROUP			
		4;0 to 4;8 yrs n=3	5;0 to 5;6 yrs n=5	6;1 to 6;7 yrs n=2	4;0 to 6;7 yrs n=10
[paki]	*Min. & Max. Dur.*	52 to 145ms	39 to 195ms	100 to 133ms	39 to 195ms
	Range (Max.- Min.)	93ms	156ms	33ms	156ms
	Mean	106ms	103ms	117ms	107ms
	STDEV	27.1	44.4	10.3	35.1
	CfV	0.26	0.43	0.09	0.33
[baki]	*Min. & Max. Dur.*	92 to 169ms	78 to 191ms	83 to 133ms	78 to 191ms
	Range (Max.- Min.)	77ms	113ms	50ms	113ms
	Mean	121ms	131ms	115ms	125ms
	STDEV	21.9	32.8	17.1	27.6
	CfV	0.18	0.25	0.15	0.22
[tasə]	*Min. & Max. Dur.*	102 to 219ms	88 to 214ms	88 to 164ms	88 to 214ms
	Range (Max.- Min.)	117ms	126ms	76ms	126ms
	Mean	166ms	158ms	135ms	156ms
	STDEV	38.3	28.2	24.9	32.3ms
	CfV	0.23	0.18	0.18	0.21
[dasə]	*Min. & Max. Dur.*	145 to 209ms	125 to 261ms	128 to 197ms	125 to 261ms
	Range (Max.- Min.)	64ms	136ms	69ms	136ms
	Mean	174ms	174ms	156ms	171ms
	STDEV	15.2	39	20.4	30.6
	CfV	0.09	0.22	0.13	0.18
[tɔpi]	*Min. & Max. Dur.*	84 to 164ms	63 to 194ms	88 to 138ms	63 to 194ms
	Range (Max.- Min.)	80ms	131ms	50ms	131ms
	Mean	116ms	123ms	110ms	118ms
	STDEV	18.2	40.8	16.1	31.4
	CfV	0.16	0.33	0.15	0.27
[dɔpi]	*Min. & Max. Dur.*	88 to 183ms	63 to 200ms	100 to 148ms	63 to 200ms
	Range (Max.- Min.)	95ms	137ms	48ms	137ms
	Mean	127ms	122ms	115ms	122ms
	STDEV	24.2	41.7	14	32.7
	CfV	0.19	0.34	0.12	0.27
[tək]	*Min. & Max. Dur.*	55 to 114ms	47 to 181ms	73 to 109ms	47 to 181ms
	Range (Max.- Min.)	59ms	134ms	36ms	134ns
	Mean	86ms	111ms	93ms	100ns
	STDEV	19.6	43	12.3	34.3s
	CfV	0.23	0.39	0.13	0.34
[dək]	*Min. & Max. Dur.*	94 to 170ms	42 to 253ms	92 to 184ms	42 to 253ms
	Range (Max.- Min.)	76ms	211ms	92ms	211ms
	Mean	132ms	143ms	126ms	136ms
	STDEV	23	67.3	28.3	50.6
	CfV	0.17	0.47	0.22	0.37

ABBREVIATIONS: Min.=Minimum Max.=Maximum STDEV=Standard deviation CfV=Coefficient of variation yrs=Years n=Number ms=Milliseconds Dur=Duration

TABLE 4.20 (-CONTINUED): SPECIFIC AGE GROUP STATISTICS FOR FVD AND VARIABILITY OF FVD

TARGET WORD	MEASURE	AGE GROUP			
		4;0 to 4;8 yrs n=3	5;0 to 5;6 yrs n=5	6;1 to 6;7 yrs n=2	4;0 to 6;7 yrs n=10
[ka̲tə]	*Min. & Max. Dur.*	94 to 153ms	86 to 198ms	91 to 161ms	86 to 198ms
	Range (Max.- Min.)	59ms	112ms	70ms	112ms
	Mean	125ms	125ms	132ms	126ms
	STDEV	20.5	32.3	23.6	27.2
	CfV	0.16	0.16	0.26	0.22
[fə̲nəx]	*Min. & Max. Dur.*	70 to 141ms	53 to 263ms	52 to 128ms	52 to 263ms
	Range (Max.- Min.)	71ms	210ms	76ms	211ms
	Mean	120ms	140ms	86ms	123ms
	STDEV	21.5	65.5	30.1	53.1
	CfV	0.18	0.47	0.35	0.43
[knə̲bəl]	*Min. & Max. Dur.*	78 to 167ms	78 to 206ms	72 to 133ms	72 to 206ms
	Range (Max.- Min.)	89ms	128ms	61ms	134ms
	Mean	123ms	126ms	102ms	120ms
	STDEV	25	30	16	27.7
	CfV	0.2	0.24	0.16	0.21
[klɔ̲ki]	*Min. & Max. Dur.*	56 to 114ms	58 to 163ms	58 to 120ms	56 to 163ms
	Range (Max.- Min.)	58ms	105ms	62ms	107ms
	Mean	93ms	95ms	96ms	95ms
	STDEV	14.9	31.9	17.3	24.9
	CfV	0.16	0.34	0.18	0.26
[blɔ̲ki]	*Min. & Max. Dur.*	75 to 133ms	70 to 192ms	48 to 134ms	48 to 192ms
	Range (Max.- Min.)	58ms	122ms	86ms	144ms
	Mean	104ms	111ms	92ms	105ms
	STDEV	19.1	34.9	29.5	31.1
	CfV	0.18	0.31	0.32	0.3

ABBREVIATIONS: Min.=Minimum Max.=Maximum STDEV=Standard deviation CfV=Coefficient of variation yrs=Years n=Number ms=Milliseconds Dur=Duration

4.7.1. DESCRIPTION AND DISCUSSION OF FIRST-VOWEL DURATION (FVD) RESULTS

4.7.1.1. Description of age-related trends in performance for FVD

From the data in Table 4.20 it can be seen that in two of the thirteen target words, namely [tasə] and [dɔpi], the four-year-olds displayed the longest mean FVD duration, followed by the five-year-olds (second longest) and the six-year-olds with the shortest mean FVD. This finding indicated an *increase in mean duration*

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with an increase in age, which is a tendency frequently observed in previous studies of segmental duration in children.

Data for [klɔki] however, indicated an *increase in mean FVD with an increase in age*, which is in contrast with most previous research findings. The average statistics for the age groups (for all the target words combined) are presented in Table 4.21, and it can be seen that the difference between the mean FVD of the age groups was as follows: difference between mean FVD of four and five-year-olds: *5ms*, difference between mean FVD of four and six-year-olds: *9ms*, difference between mean FVD of six and five-year-olds: *14ms*. Data in Table 4.20 for [klɔki] showed that the difference between the means of the age groups only differed between one and three milliseconds, which is much smaller than the average differences in means between the age groups across target words. It can thus be argued that since the difference in mean FVD's between the age groups was so small, this can be regarded as a case of *similarity* in performance by the three age groups, rather than a case of increase in mean FVD with an increase in age.

TABLE 4.21: SUMMARY OF AGE GROUP PERFORMANCE WITH REGARD TO MEAN FVD AND VARIABILITY (CALCULATED ACROSS ALL THE TARGET WORDS)

MEASURE	GROUP			
	Subjects as a Group (n=10)	4-year-olds n=3	5-year-olds n=5	6-year-olds n=2
Min. and Max. Duration	39 to 263ms	52 to 219ms	39 to 263ms	48 to 197ms
Range (Max - Min)	224ms	167ms	224ms	149ms
Mean Duration (ms)	123ms	123ms	128ms	114ms
STDEV	40.2	33.2	46.8	27.9
CfV	0.33	0.27	0.37	0.25

ABBREVIATIONS: Min.=Minimum Max.=Maximum STDEV=Standard deviation CfV=Coefficient of variation yrs=Years n=Number

In spite of the absence of consistent age-related trends in FVD throughout the material, further analysis of the data in Table 4.20 did indicate a general trend for the oldest age group to show the shortest mean FVD's most often. Table 4.22 presents a summary of age group performance concerning mean duration position (i.e. longest or shortest FVD) for the material. It indicated that the age group that displayed the *longest* mean FVD-position most often (thus in most target words), was the five-year-old group (7.5 times), followed by the six-year-olds group (3 times) and the four-year-olds (2.5 times). In contrast with most previous research findings, the youngest age group thus did *not* obtain the overall longest mean FVD. However, in accordance with previous findings, the *oldest age* group did obtain the *shortest* mean FVD-position most often (9 times), compared to the 2.5 times of the four-year-olds and the 1.5 times of the five-year-olds.

TABLE 4.22: SUMMARY OF AGE GROUP PERFORMANCE IN TERMS OF MEAN DURATION POSITION OBTAINED ACROSS TARGET WORDS

Position *	***Longest* Mean Duration Position**	***Middle* Mean Duration Position**	***Shortest* Mean Duration Position**
Age group that obtained this position the <u>most</u>:	5 year-olds (7.5 times)	4 year-olds (7 times)	6 year-olds (9 times)
Age group that obtained this position <u>second most</u>:	6 year-olds (3 times)	5 year-olds (3 times)	4 year-olds (2.5 times)
Age group that obtained this position the <u>least</u>:	4 year-olds (2.5 times)	6 year-olds (once)	5 year olds (1.5 times)

* *NOTE: a 0.5 score was assigned when the position was shared with another age group)*

The same tendency was also observed when the mean FVD's of the different age groups for all the target words combined were summarized (Table 4.21). The six-year-olds showed a shorter mean FVD-value than the four and five-year-olds. Further, the means for the four and five-year-olds differed only slightly (i.e. 5ms), while a bigger difference existed between the means of the six and five-year-olds (i.e. 14ms), and the six and four-year-olds (i.e. 9ms) respectively.

FVD-results for the rest of the target words indicated mixed individual and group performance, with *no clear age-related trends* in performance. Mean FVD-results for the different subjects (calculated from the durations of all the target words combined) generally also did not show clear age-related trends (See Tables 4.19 and 4.23). Although the two *longest* mean FVD's across words for example, were displayed by five-year-olds (S8 and S4), the *shortest* mean FVD was also displayed by a five-year-old (i.e. S7). A strong tendency for *individual* performance rather than age-related performance was thus indicated by these

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data. The mean FVD's of the two five-year-olds, S8 (longest mean vowel duration) and S7 (shortest mean vowel duration) differed as much as 71ms, indicating a big difference in performance. The two *shortest* individual mean FVD's however, were obtained by two of the *oldest* subjects i.e. S10 (6;7 yrs) and S7 (5;4yrs), which corresponds with the previous described tendency for older subjects to generally show shorter FVD's.

TABLE 4.23: MEAN FVD-DATA FOR THE TEN SUBJECTS (CALCULATED ACROSS TARGET WORDS)

Subjects	Mean First-vowel Duration (FVD) Across Words
S8 (5;6 years)	169ms
S4 (5;0 years)	165ms
S3 (4;8 years)	131ms
S9 (6;1 years)	127ms
S2 (4;1 years)	120ms
S1 (4;0 years)	119ms
S5 (5;3 years)	103ms
S6 (5;4 years)	103ms
S10 (6;7 years)	100ms
S7 (5;4 years)	98ms

4.7.1.2. Summary and discussion of general FVD-results

The *main normative indications* that emerged from the FVD-data can be summarized as follows. Firstly, a tendency existed for the *older* subjects (mostly six-year-olds) to display *shorter* FVD's than younger subjects, but in contrast the youngest subjects did not always show the longest FVD's. Secondly, the effect of an increase in mean FVD with increased age was observed, but it occurred only twice (in two target words out of thirteen). Afrikaans-speaking children in the age range 4;0 to 6;7 years thus did not show clear age-related trends (i.e. decrease in duration with increased age) in performance with regard to FVD throughout the material. Thirdly, results indicated very *individual* trends in performance.

In correspondence with the general observations of this study, previous findings regarding sensorimotor speech timing control cumulatively indicated that children generally display longer segmental and speech gestural durations than adults, and that older children tend to display shorter segmental or speech gestural durations than younger children (DiSimoni,1974:a;b; Tingley & Allen,1975; Kent & Forner,1980; Smith et al.,1983; Rimac & Smith,1983; Chermak & Schneiderman,1986; Walker et al.,1992; Nittrouer,1993; Robb & Tyler,1995; Smith & Kenney,1998). It should be noted that this conclusion is based on a wide variety of data characterized by more methodical differences than similarities in terms of instrumentation used (acoustic vs. kinematic studies), ages of subjects, material used (spontaneous speech, sentences, nonsense syllables, non-words vs. meaningful words, consonants/vowels in different word positions, clusters), and the aspects of sensorimotor control that were investigated. Only limited comparison and cautiously offered explanations are thus possible. Some of the few studies comparable to this study (i.e. DiSimoni,1974:a;b; Smith,1978; Kent & Forner,1980) generally found a more profound decrease in segmental duration with an increase in age than was observed in this study, but did not report on individual trends in their results, which again limits comparison.

Some explanations can be considered for the fact that the results of this study did not show FVD to decrease more profoundly with increased age. It can be suggested that the segmental duration differences in normal children in the clinically relevant age range of 4;0 to 6;7 years may be less intense, since only one-year differences between age groups occur. Information is not yet available regarding the specific performance of four, five, and six-year-olds on segmental duration tasks. Existing comparable studies that reported more profound segmental duration decreases with increased age, studied age groups which differed mostly two to three years and reported on a wide variety of age groups e.g. Tingley and Allen (1975): five, seven, nine-year-olds and adults, Smith (1978) two to four-year-olds and adults, DiSimoni (1974:a;b): three, six, nine-year-olds and adults), Kent and Forner (1980): four, six, twelve-year-olds and adults, Walker et al. (1992): three to five-year-olds, Smith (1994): five, eight and 11-year-olds. Comparable information regarding segmental duration in normal

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children in the clinically important age range of 4;0 to 7;0 years is thus limited. This is mostly the result of the fact that the aims of previous research were to determine *general trends* in normal sensorimotor speech development through childhood, and not necessarily to concentrate on specific clinical-relevant age ranges. This study's aim was different, since it intentionally investigated sensorimotor speech control skills in the age range 4;0 to 7;0 years, in order to establish a general normative database to which the sensorimotor speech control skills of children with DSD can eventually be compared with.

Research findings regarding the development of speaking rate highlight the possibility that developmental rate changes may not necessarily proceed on a yearly basis (although again no results are available specifically for four, five and six-year-olds). Pindzola, Jenkins and Lokken (1989) for example, did not find significant differences in the speaking rates of three, four and five-year-olds (conversational speech) and suggested that speaking rate might rather increase sporadically at certain age intervals. Kowal, O'Connel and Sabin (1975) found a developmental increase in conversational rates at two-year intervals, when studying children in kindergarten trough high school, while Amster and Starkweather (1985) found significant rate differences between two year-olds and preschoolers, but non-significant rate differences among three, four, and five-year-olds. Smith (1978) also found that although his data showed a general decrease in segmental duration with decreased age, the adults vs. two-year-old comparisons constituted the primary age-related differences (rather than the two- and four-year-olds). Although the general assumption is that children are able to increasingly produce faster segmental durations as they grow older, results are still inconclusive in indicating possible *stages* of sensorimotor speech development in children (Netsell,1986; Smith et al.,1995). It is thus still uncertain when major developmental changes in segmental duration exactly occur. Results of this study may suggest that the 4;0 to 6;7 year age-period is not be characterized by *major* developmental changes in first-vowel duration (FVD) in Afrikaans-speaking children, although minor differences may be present between individuals.

It is also possible that more individual and age-unrelated differences than previously found may be observed in children's sensorimotor speech timing control, if data are not necessarily pooled according to *age*, if data are more purposefully examined for *individual trends* and if more *longitudinal* studies are performed. In a recent longitudinal study Smith and Kenney (1998) reported on individual trends in development of several acoustic parameters in seven subjects. Syllable duration measured at ages eight, ten and eleven did not show a *consistent* decrease in segmental duration across time for all seven subjects. Most of them however, did show *shorter* durations when comparing the first and last measurement. Smith and Kenney (1998) found that the individual developmental patterns observed were not linear in nature and further, subjects did not 'mature' on the same schedule regarding different aspects of sensorimotor speech control. They also concluded that the various structures and systems associated with speech production do not necessarily develop in comparable ways or at similar rates. In most existing acoustic studies findings are based on *averages* across a number of children belonging to different age groups, which makes it difficult to know what the various *courses of development* for different individuals will be (Smith & Kenney,1998). Since most previous acoustic studies on speech production development involved cross-sectional or group studies, existing results "... represents a somewhat generalized or idealized description of changes found to occur across groups of children of different ages." (Smith & Kenney:1998:96).Von Hofsten (1989:952-953) also commented that "...the rate of development is different for different subjects. Some develop quickly, whereas others develop slowly. One and the same child may develop quickly at certain ages and slowly at others...Therefore pooling data for groups of individuals of the same age will 'smear' the developmental function, hide important transitions, and make it look smooth and uneventful.".

Individual trends in performance regarding sensorimotor speech timing control may thus be expected rather than considered exceptional. As was the case with diadochokinetic rate data in this study, it may thus be more appropriate to use the *range* of FVD-values exhibited by the subjects as a group for normative comparison than specific age group data. This issue will be more extensively discussed under the heading of variability in segmental duration and in Chapter 5 where the results of the different aims will be considered together.

4.7.1.3. Description and discussion of FVD-data for voiced/voiceless word pairs

Although the investigation of *contextual influences* on FVD was not a main focus of this study (i.e. not statistically compared), the material was varied to some extent to allow for the possible emergence of contextual differences (See Chapter 3). One contextual effect emerged from the FVD-data. When the mean FVD obtained by the subjects as a group for the different words were examined, it was observed that in the case of all the voiced/voiceless initial stop word pairs, the duration of a *vowel preceded by a voiced plosive* (e.g. [a] in [baci]) were longer than the duration of the same vowel *preceded by a voiceless plosive* (e.g. [a] in [paci] (see Table 4.24).

TABLE 4.24: MEAN FVD'S OF THE SUBJECTS AS A GROUP FOR VOICED/VOICELESS TARGET WORD PAIRS

TARGET WORDS	Mean FVD for the Subjects as a Group	Difference in Mean FVD
[paci] [baci]	107ms 125ms	18ms
[tasə] [dasə]	156ms 171ms	15ms
[tɔpi] [dɔpi]	118ms 122ms	4ms
[tək] [dək]	100ms 136ms	36ms
[klɔki] [blɔki]	95ms 105ms	10ms

Although no direct comparable studies to this study could be identified, adults (e.g. Peterson & Lehiste,1960; Klatt,1975) and children (e.g. DiSimoni,1972 in Smith,1978; Krause,1982; Beardsley & Cullinan,1987) had been shown to produce longer (about 100ms) English vowels before voiced than before voiceless *word-final* English consonants. The results of this study thus correspond to some extent to these findings, although different languages and consonant word positions are applicable. The difference between the overall mean FVD for all ten subjects of *vowels preceded by a voiced* consonant *and*

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vowels preceded by a voiceless consonant ranged from four to 36ms. These values are much smaller than the values reported for English and more like those reported for Russian and Korean (Smith,1978). One explanation for the durational differences in the case of bilabial stops, is that the closing gestures for voiceless bilabial stops (in terms of jaw and lip closure/velocities) had been found to be accomplished more rapidly than for voiced stops (Chen in Smith,1978; MacNeilage & Hanson in Smith,1978). Further investigation regarding contextual effects on vowel duration in Afrikaans is needed before any conclusions can be reached regarding the influence of *pre-ceding consonantal voicing* on first-vowel duration, since so many linguistic and phonetic factors may be influential in segmental duration (Kent & Forner,1980).

4.7.2. DESCRIPTION AND DISCUSSION OF VARIABILITY OF FIRST-VOWEL DURATION (FVD) RESULTS

4.7.2.1. Description of variability of FVD-results

In terms of *intra-individual variability* in vowel duration, (i.e. the performance of the individual subjects for the different target words), the subjects displayed different standard deviations and CfV-values (i.e. coefficient of variation which is the standard deviation divided by the mean, see Chapter 3) for every target word (see Table 4.19). Irregular individual performance patterns and a wide range of FVD occurred across the material for all the subjects.

The CfV-values obtained by the subjects, based on FVD obtained for all the words together (65 utterances each), are illustrated in Figure 4.2 and give some indication of *inter-subject* (or inter-individual) variability in FVD. The lowest CfV (thus the least variability) was displayed by S9 (6;1 years) and the highest CfV (greatest variability) by S7 (5;4 years). Based on earlier hypotheses regarding the nature of the relationship between duration and variability (e.g. Kent & Forner,1980; Chermak & Schneiderman,1986; Crystal & House,1988), it may be considered surprising that the subject who scored the shortest mean FVD across words (see previous section) demonstrated the most variability in FVD.

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According to these hypotheses, S9 would rather have been expected to show very little variability in terms of FVD. However, more recent research indicated a different relationship between variability and duration than previously expected (e.g. Smith,1994), as will be illustrated and discussed in-depth later in this section.

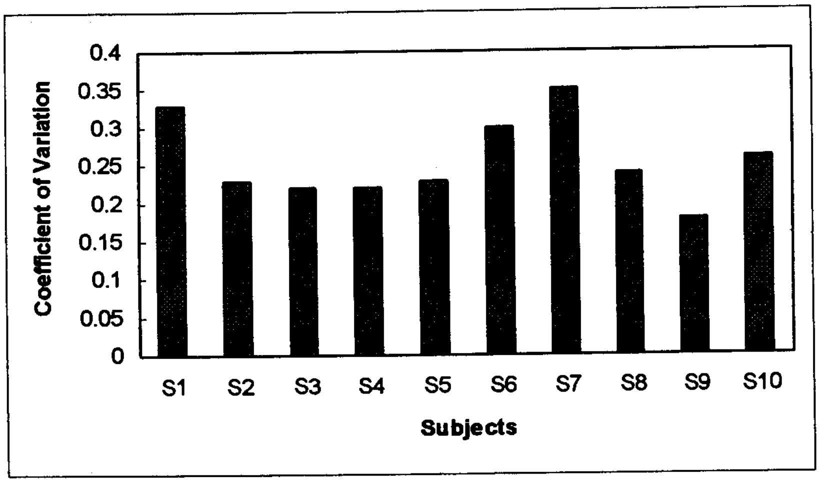

FIGURE 4.2: COEFFICIENTS OF VARIATION (CfV'S) FOR EACH SUBJECT, AS CALCULATED FROM THEIR FIRST VOWEL DURATIONS FOR ALL THE MATERIAL (i.e. 65 UTTERANCES EACH)

Age group performance concerning mean FVD and variability across age groups are presented in Table 4.21. These data indicated that the subjects as a group (mean age=5;2 years) obtained a wide distribution (from 39ms to 263ms across the thirteen target words, mean=123ms, STDEV=40ms. Results thus indicated a wide range (range=224) of FVD for Afrikaans-speaking children aged 4;0 to 6;7 years.

In terms of *inter-subject variability* of FVD, no clear *age-related trends* could be identified from the data. The youngest subject (S1) did show a very high CfV-value (indicating great variability) compared to eight other subjects, but the general finding in research relating to variability in segmental duration, which is that variability tends to decline with an increase in children's age, was not clearly present in this individual data. Results rather indicated very individual trends in performance (see Figure 4.2 and Table 4.19).

Age group results (Table 4.21) further indicated that the five-year-olds had the largest CfV-value (i.e. 0.37, displaying the greatest variability) and the six-year-olds the smallest (i.e. 0.25, displaying least variability in vowel duration). These observations were confirmed by the summary analysis of the CfV-position scored by the age groups (displayed in Table 4.25). The six-year-olds obtained the lowest CfV-value the most (across the thirteen target words) and the five-year-olds scored the highest CfV-value the most. Based on previously reported age trend results, the youngest age group would have been expected to show the least variability in FVD. It should be noted that a contributing factor to the five-year-olds showing the greatest variability in FVD and not the four year-olds, could be the fact that this age group had two more subjects than the four-year-olds, which increased the chance for a wider range of performance. Other possible contributing factors will be discussed further on.

TABLE 4.25: SUMMARY OF AGE GROUP PERFORMANCE IN TERMS OF COEFFICIENT OF VARIATION (CfV) POSITION OBTAINED ACROSS TARGET WORDS

Position	Highest CfV (most variability)	Middle CfV	Lowest CfV (least variability)
Age group that obtained this position the <u>most</u>:	5 year-olds (11 times)	4 year-olds (6 times)	6 year-olds (6.5 times)
Age group that obtained this position <u>second most</u>:	-	6 year-olds (5 times)	4 year-olds (5.5 times)
Age group that obtained this position the <u>least</u>:	6 year-olds (once) 4 year-olds (once)	5 year-olds (never)	5 year-olds (once)

* *NOTE: a 0.5 score was assigned when the position was shared with another age group*

4.7.2.2. Summary and discussion of variability of FVD-results

In summary, results regarding variability in FVD firstly indicated very individual trends in performance, with children in the same age group sometimes displaying contrasting results. Secondly, an interesting finding in the individual data was that S7, who scored the lowest mean FVD across words (see previous section), displayed the greatest variability in FVD, while S9 who ranked fourth highest on mean FVD, displayed the least variability. Generally speaking, subjects with shorter segmental durations will be expected to show less variability, based on the traditional view (e.g. Bruner,1973) that skilled motor performance is marked

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by a faster execution rate and less variability (i.e. greater consistency in performance).

Thirdly, age groups results indicated a tendency for the oldest age group (six-year-olds) to show the least variability in vowel duration, which is in agreement with findings from previous acoustic studies (e.g. DiSimoni,1974:a;b; Tingley & Allen, 1975; Kent & Forner,1980; Smith et al.,1983). However, the most variability in FVD was displayed by the five-year-olds and not as would have been expected from generally observed trends in previous research, by the youngest age group in the study.

The following explanations can be considered for the observed contrasting performance by subjects of the same age, and the fact that the effect of a decrease in variability with increased age was not consistently observed. First, it has to be pointed out that although the finding that variability in sensorimotor speech timing control tends to decrease with age was a fairly consistent result in previous studies, *exceptions* in individual and group performance have been simultaneously reported. Tingley and Allen (1975) noted a wide variation within age groups (five, seven, nine and 11-year-olds), suggesting that there appears to be clear individual differences in children's timing control. Smith (1978) mentioned that in several instances the four-year-olds in his study revealed less variability than even adults. Kent and Forner (1980) also found considerable inter-subject differences in phrase repetition tasks in four-year-old children and a weak developmental trend in terms of individual variability. They noted that although the four-year-old group generally showed large inter-subject variability, some of them displayed standard deviations within the adult range. They concluded that "...some of these young children are capable of much more reliable control over speech production than the others." (Kent & Forner,1980:161). Stathopoulos (1995) also argued that children (four, six, eight, ten, twelve years) are not consistently more variable than adults. She found that there were significant variability differences for some measures between children and adults, and that it was primarily four-year-olds that accounted for the increased variability. "Of the 15 measures made, 4 year-olds were significantly more variable than adults on only eight. And on one measure, lung volume termination, 4-, 6- and 8- year-olds were significantly less variable than the adults. There did not appear to be any pattern to the variability across age." (Stathopoulos,1995:75).

Such findings would be in line with recent research suggesting the possible very *individual* nature of children's sensorimotor speech skills (Goodell & Studdert-Kennedy,1993; Nittrouer,1993;1995; Smith & Goffman,1998; Smith & Kenney,1998). Smith and Kenney (1998:105) stated that "....the rate and pattern of change for individual parameters and/or the periods during which such changes occur may differ considerably among subjects and across ages.". Smith (1994:173) hypothesized that "...two children of the same age and with comparable developed nervous systems could manifest different amounts of variability if one were more inclined than the other to explore the capabilities of his or her vocal tract.". A great amount of data is still needed to clarify the issue of *individuality* in sensorimotor speech timing control and explanations remain for the most part hypothetical. What seems to be needed is less of a focus on averaged group results and more focus on *individual trends* in performance and longitudinal data on how individual children's sensorimotor speech control changes over time. The issue of individuality in sensorimotor speech control development will be further discussed in Chapter 5.

Based on earlier hypotheses of the relationship between speech timing variability and segmental duration, some of the individual results on FVD variability may be considered somewhat surprising, since some researchers were of opinion that variability might essentially be a consequence of duration and that the two concepts are highly correlated with one another (i.e. mathematical hypothesis e.g. Chermak & Schneiderman,1986; Crystal & House,1988). First, the subject who scored the shortest mean FVD displayed the greatest variability, and secondly, the subject who displayed the least variability, ranked fourth highest on mean FVD. Based on the view that duration and variability are related, subjects who display shorter segmental durations will be expected to show less variability, and vice versa.

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However, conflicting opinions exist regarding the matter, since it has also been theorized that variability is relatively *independent* of duration (neuromotor hypotheses e.g. Smith,1992). Smith (1992) argued that variability and duration may each provide somewhat *different* information about sensorimotor speech development. This would imply that a subject can indeed perform very differently on these two aspects. Smith (1994) conducted one of the most extensive studies up to date regarding the nature of the relationship between segmental duration and variability, which confirmed his earlier hypothesis. On closer examination of individual results Smith (1994) observed that two to three subjects in each of his subject groups (a total of five subjects per age group), did not comply with the prediction that shorter segment durations result in reduced variability. Smith (1994:171) concluded that his "..assortment of findings from a number of different perspectives.." indicated that variability and duration in acoustic segmental measurements may not be very closely related (although some degree of relationship may exist).

Smith's (1994) findings also showed that variability may reach adult-levels *later* in the process of development than duration does, thus that the two may not develop in tandem. This implies that a child can reach maturity in one aspect of sensorimotor speech control but not in another. Recently Stathopoulos (1995) and Smith and Kenney (1998) have both proposed that sensorimotor speech development may be non-linear and multi-modal, thus that different speech parameters/components develop at different rates. According to this point of view, the contrasting performance of S7 and S9 on FVD and variability respectively, may not be so surprising at all. It may simply reflect different components (i.e. aspects) of sensorimotor speech development. Yet, to presently explain these findings satisfactorily and conclusively remains very difficult in the light of the controversy and great amount of speculation still involved regarding the nature of the relationship between variability and duration in sensorimotor speech control.

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4.8. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM SEVEN: VOICE ONSET TIME (VOT)

The goal of this sub-aim was to obtain normative, acoustic indications of the nature of *voice onset time (VOT)-values* of voiced and voiceless Afrikaans stops in normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years, as measured in repeated utterances of the same word.

The results of this aim will be described and discussed with reference to the *mean individual* VOT-data summarized in Table 4.26 and the *group* VOT-data presented in Table 4.27, where data for the different material were pooled together based on voicing. Data will be described and discussed in the same order as the data groupings in Table 4.27 i.e. data *for word-initial voiced stops* [b] and [d], followed by data for *word-initial voiceless stops* [p], [t], and [k], data for *voiced stop [b] in cluster [bl],* and data for *voiceless stop [k] in clusters [kl] and [kn].* Finally, VOT-results for the *combined voiced* stop contexts (i.e. word-initial and cluster contexts) and *combined voiceless* stop contexts (word-initial and cluster contexts) will be described.

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TABLE 4.26: INDIVIDUAL VOICE ONSET TIME (VOT) DATA (MEANS AND STDEV'S)

TARGET WORD	VALUE	S1 4;0	S2 4;1	S3 4;8	S4 5;0	S5 5;3	S6 5;4	S7 5;4	S8 5;6	S9 6;1	S10 6;7
[paki]	**Mean VOT(ms)**	+11	+9	+5	+12	+8	+18	+7	+5	-4	+11
	STDEV	3.7	3.9	1.9	3.2	1.3	5	2.4	3.6	6.9	1.6
[baki]	**Mean VOT (ms)**	+11	+11	-16	+6	+7	+7	0	+3	-185	-42
	STDEV	7.2	4.7	26.2	1.1	1.4	2.4	4.4	2.6	136.9	36.8
[tasə]	**Mean VOT (ms)**	+12	+10	+9	+9	+10	+13	+7	+12	+12	+21
	STDEV	3.9	3.2	1.8	3.2	3	5.7	3.4	1.8	2.4	6.4
[dasə]	**Mean VOT (ms)**	+13	+13	-6	+7	+13	+10	+10	+6	-44	-7
	STDEV	3.3	4.6	25.5	3.4	1.8	4.1	1.8	3.8	74.6	53.9
[tɔpi]	**Mean VOT (ms)**	+8	+14	+9	+6	+10	+11	+7	+7	+11	+12
	STDEV	1.3	1.7	1.9	2.8	2	5.1	3	1.3	0.7	1.8
[dɔpi]	**Mean VOT (ms)**	+13	+12	-37	+8	+10	+4	+7	+5	-253	0
	STDEV	6.2	2.8	64.8	1.1	2	19.8	2	5.1	93.6	34.6
[tək]	**Mean VOT (ms)**	+9	+11	+13	+14	+11	+12	+8	+16	+23	+39
	STDEV	1.4	2.3	3.9	3.7	1.3	5.3	4.6	6.5	6.3	42.7
[dək]	**Mean VOT (ms)**	+17	+12	+8	+10	+14	+9	+12	+16	-170	-79
	STDEV	4.8	2.4	5.3	1.3	3.4	9.6	2.9	3	94.6	26
[katə]	**Mean VOT (ms)**	+12	+22	+23	+14	+22	+20	+13	+17	+23	+24
	STDEV	4.2	4	14.8	4.9	4.3	7.6	1.4	3.7	6.3	7.7
[knəbəl]	**Mean VOT (ms)**	+26	+12	+55	+67	+27	+76	+23	+24	+35	+58
	STDEV	14.5	3.9	56	25.5	6.8	35.6	6.5	8.6	10.7	48.9
[klɔki]	**Mean VOT (ms)**	+23	+26	+32	+31	+23	+48	+20	+35	+33	+19
	STDEV	6.9	13.9	12.4	7.1	5.5	12.6	11.3	12.9	11.7	6.3
[blɔki]	**Mean VOT (ms)**	+26	+17	-7	+32	+12	+3	+11	-4	-1	0
	STDEV	25.8	10.1	48.7	12.9	5	15.8	5.9	25.3	3.2	23.2

ABBREVIATIONS: S=Subject ms=Milliseconds STDEV=Standard deviation VOT=Voice onset time

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TABLE 4.27: GROUP DATA FOR VOICE ONSET TIME (VOT) POOLED ACCORDING TO VOICING, WITH CLUSTERS PRESENTED SEPARATELY

WORDS FOR WHICH VOT-RESULTS WERE POOLED TOGETHER	MEASURE	AGE GROUPS			
		4;0 to 4;8 yrs n=3	5;0 to 5;6 yrs n=5	6;1 to 6;7yrs n=2	Subjects as a Group n=10
Words with initial VOICED stops: [baki] [dasə] [dɔpi] [dək]	*Min. & Max.VOT*	-120 to +23ms	-31 to +25ms	-384 to +30ms	-384 to +30ms
	Range:	143ms	56ms	414ms	414ms
	Mean:	+4ms	+8ms	-97ms	-14ms
	STDEV:	25	6	113	67
Words with initial VOICELESS stops: [paki] [tasə] [tɔpi] [tək] [katə]	*Min. & Max. VOT*	+2 to +47ms	+2 to +27ms	-10 to +114ms	-10 to +114ms
	Range:	45ms	25ms	124ms	124ms
	Mean:	+12ms	+11ms	+17ms	+13ms
	STDEV:	6	6	17	10
Clusters with initial VOICED stops: [blɔki].	*Min. & Max VOT*	-94 to +55ms	-41 to +50ms	-30 to +23ms	-94 to +55ms
	Range:	149ms	91ms	53ms	149ms
	Mean:	+12ms	+11ms	0ms	+9ms
	STDEV:	33	18	16	23
Clusters with initial VOICE-LESS stops: [knəbəl] [klɔki]	*Min. & Max VOT*	+8 to +152ms	+8 to +108ms	+11 to +142ms	+8 to +152ms
	Range:	144ms	100ms	131ms	144ms
	Mean:	+29ms	+37ms	+36ms	+35ms
	STDEV:	26	24	28	25

ABBREVIATIONS: Min.=Minimum Max.=Maximum VOT=Voice onset time STDEV=Standard deviation ms=Milliseconds yrs=Years

4.8.1. DESCRIPTION AND DISCUSSION OF VOT-RESULTS OF WORDS STARTING WITH VOICED STOPS [b] AND [d] (i.e. [baki], [dasə], [dɔpi] AND [dək])

The VOT-results obtained for voiced plosives [b] and [d] will be discussed with reference to the data in Table 4.27 (where VOT-values for words starting with these sounds were pooled together), and Figure 4.3 which visually illustrates the minimum and maximum VOT-values for the different age groups and material.

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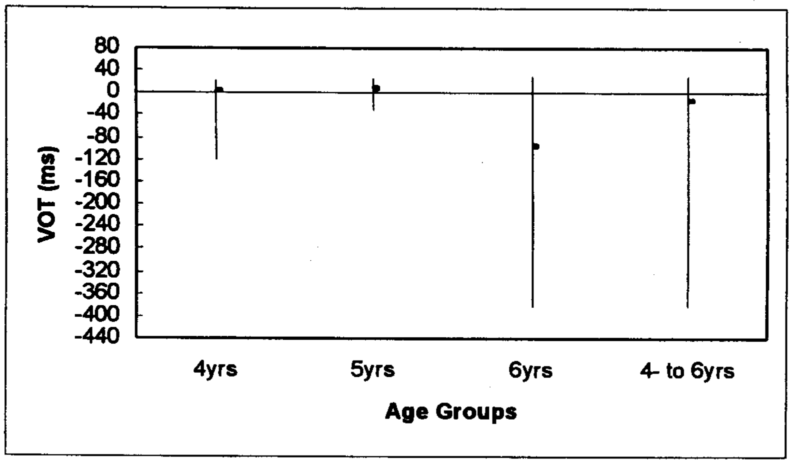

FIGURE 4.3: AGE GROUP VOT-DATA (i.e. MINIMUM, MEAN, MAXIMUM) FOR VOICED INITIAL STOPS [b] AND [d]

From the results for words starting with *voiced stops* [b] and [d] it can be seen that the subjects as a group showed a wide range of VOT-values (-384ms to +30ms), although the individual means only ranged from –97ms to +8ms (Table 4.27). The wide range of overall VOT-values was mostly the result of the very negative VOT's displayed by the six-year-olds (mean of -97ms, see Table 4.27 and Figure 4.3). Individual mean VOT-data (Table 4.26) showed that unlike any of the younger subjects, S9 and S10 displayed long voicing *leads* in almost all of their productions of words starting with voiced stops. A summary of subject and age group percentages for the occurrence of *mean voicing lead* are presented in Table 4.28 (calculated from data in Table 4.26).

It can be seen from the data in Table 4.28 that S9 displayed only negative mean VOT's or voicing lead (i.e. 100%) for voiced stop productions, while S10 showed voicing lead in 75% of his mean VOT's. In contrast, results for the younger subjects indicated that S3 (75% of his mean VOT's for voiced stops) was the only other subject who displayed any mean VOT voicing leads for voiced stops. However, his VOT's were not as negative as those of S9 and S10 (see Table 4.26).

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TABLE 4.28: SUBJECT AND GROUP PERCENTAGES FOR MEAN VOICING LEAD IN WORDS WITH VOICED INITIAL STOPS

SUB-JECT	Number of negative VOT-means (voicing lead) in words with initial voiced stops	Percentage	PERCENTAGE OF MEAN VOICING LEAD FOR THE AGE GROUPS	PERCENTAGE OF MEAN VOICING LEAD FOR THE SUBJECTS AS A GROUP
S1	0	0	**Four-year-olds:** 25%	**4;0 to 6;7-years-old**: 25%
S2	0	0		
S3	3	75		
S4	0	0	**Five-year-olds:** 0%	
S5	0	0		
S6	0	0		
S7	0	0		
S8	0	0		
S9	4	100	**Six-year-olds:** 88%	
S10	3	75		

The four-year-olds displayed mean voicing lead in 25% of their productions of word-initial stops, the five-year-olds displayed no negative mean voicing leads and the six-year-olds in contrast, displayed 88% voicing lead for this context. The subjects as a group displayed mean voicing lead in 25% of word-initial voiced stops.

These findings are in agreement with those of previous English studies. Zlatin and Koenigsknecht (1976) for example found that English adults showed more frequent voicing lead productions than children and that six-year-olds showed more frequent voicing leads than two-year-olds. The infrequent lead exhibited by two-year-old children resulted in a consistently narrower range of production for voiced stops than older children and adults (Zlatin & Koenigsknecht,1976). In correspondence with these findings, data showed that the range displayed by the four and five-year-olds in this study was smaller than that of the six-year-olds (See Table 4.27 and Figure 4.3.). Results from this study thus indicated a tendency for Afrikaans-speaking subjects younger than six years, to show voicing *lag* (positive VOT's) rather than voicing *lead* (negative VOT's) in their VOT's for word-initial *voiced stops*.

VOT-values for *English* voiced stops are usually reported to fall anywhere in the range of -20 to +20ms (Kent & Read,1992). Lisker and Abramson (1964) reported adult values for *Dutch* voiced stops ranging from -145ms to -45ms.

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Dutch more closely resembles the Afrikaans-language, since both Dutch and Afrikaans have the same contrasts of voiced and voiceless unaspirated stops [p/b/d/t] and only [k] in the velar position. Lisker and Abramson (1964) reported that other than English, which displayed three sets of VOT-values for stops in their study, Dutch had mostly two, namely one set of stops with negative values and the other with zero or small positive values of VOT. In this study the mean VOT-values of four and five-year-olds were closer to the reported voiced stop VOT-values for English than those reported for Dutch, while the six-year-olds' mean VOT-value for voiced stops, appears to be more closely related to the values reported for Dutch (Table 4.27).

Consensus exists about the fact that English children's VOT-values proceed from *unimodal* to *bimodal* distributions in terms of development, first showing VOT's mostly concentrated in the *short* voicing-lag range (i.e. 0 to +39ms) and over time adding more VOT's in the *long* voicing-lag range (i.e. values of +40ms and above) (Kewley-Port & Preston,1974; Zlatin & Koenigsknecht,1976; Gilbert, 1977; Macken & Barton, 1980). It has been reported that utterance-initial voiced stops generally are not pre-voiced in English, indicating that English speakers habitually effect an oral closure when beginning an utterance with a stop (Lisker & Abramson,1964; Klatt,1975).

Results from this study indicated a possibly different developmental pattern for Afrikaans-speaking children's VOT-control. Similar to English, results from this study may indicate that VOT's for Afrikaans-speaking children's voiced stops also first show a *unimodal* distribution with VOT's concentrated in the short-lag voicing range (i.e. 0 to +39ms). However, where the English VOT bimodal distribution is characterized by an increase in *long* voicing-lag values, (i.e. VOT's of +40ms and above), results seem to indicate the opposite for Afrikaans-speaking children. Their bimodal distribution may rather be characterized by the occurrence of more VOT's in the voicing *lead* range (negative VOT's) by six years. Extensive research with larger subject groups (and both younger and older children) is needed to expand on the present findings regarding VOT-development for normal Afrikaans-speaking children though. Due to the small number of subjects per age group, age-related observations have to be considered tentatively.

Some explanation for the fact that negative voicing leads were mostly displayed by the *older* children in this study, may be gained from the physiology of stop consonant production in adults. Researchers have frequently hypothesized that articulatory movements which result in stops with *short* VOT-intervals (i.e. 0 to +39ms) might be easiest for children to accomplish. On the other hand, to produce stops with either voicing *lead* or *long* voicing-lag (i.e. above +39ms), requires more careful timing between supra-glottal and glottal articulators (Kewley,Port & Preston,1974; Gilbert,1977). Allen (1985) in a study of VOT in French children had theorized that VOT's in the voicing lead region may even be motorically more difficult for children to produce than VOT's in either the short or long-lag voicing regions. At least three separate articulatory gestures with separate innervations are needed to produce a stop consonant. These include the articulations to permit stop closure and release (labial, alveolar or velar positions), to isolate the nasal cavities at the velum and to initiate vocal fold vibration (Rothenberg,1968; Kewley-Port & Preston,1974). Other articulatory gestures in the vocal tract may also be used by adults to produce stops (Kewley-Port & Preston,1974). The nasal cavities must be isolated from the rest of the vocal tract in order to create the intraoral pressure needed to produce the stop. "Articulatory gestures required to produce *short lag stops* are velopharyngeal closure followed by the complete adduction of the vocal folds at the time of release of the supraglottal articulators, such that vocal fold oscillation begins within 20ms of release. In order to initiate vocal fold oscillation, another factor must be coincident. Oscillation of adducted folds is the result of airflow through the glottis, which in turn occurs when there is a sustained pressure drop across the glottis. When the vocal tract is unobstructed and the vocal cords are adducted, a wide range of transglottal pressure differentials and tensions in the vocal folds will result in some sort of vocal fold oscillation." (Kewley-Port & Preston,1974:203-204). However, when the vocal tract is obstructed, as during stop closure, and the vocal folds adducted, Rothenberg (1968) had theorized that oscillation will not occur or be maintained unless special articulatory mechanisms are utilized to sustain transglottal pressure drop. Special mechanisms might

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include passive enlargement of the supraglottal cavity, heightened subglottal pressure, and some nasal airflow which may comprise velopharyngeal adjustments other than simple velopharyngeal closure (Kewley-Port & Preston,1974).

Thus, for a child to successfully produce short-lag alveolar stops (i.e. VOT's between 0 and +39ms) in the initial position, the glottis may be fully closed any time during alveolar closure, providing that the velopharyngeal closure merely isolates the nasal cavities. However, to produce voicing *lead* stops (negative VOT's), the child must complete glottal closure considerably before oral release and then initiate and sustain vocal fold oscillation by the addition of other articulatory mechanisms (Kewley-Port & Preston,1974). Voicing lead stops may thus require muscle gestures in *addition* to those needed for short voicing-lag stops, which support the hypothesis that *short* voicing-lag stops may have less complex articulations than *voicing lead* productions (Kewley-Port & Preston, 1974). Based on maturity aspects, it may thus be easier for older children to produce the complex articulations resulting in voicing lead, than for younger children.

In addition, it was occasionally observed in the present study that long intervals of pre-voicing were marked by nasal sounding voicing, almost as if the child added a nasal sound to the production e.g. [mbaki] instead of [baki] or [ndək] instead of [dək]. Figure 4.4 is an example of such an instance, where S9 displayed a very negative VOT of -384ms for [baki]. It should be mentioned that this did not occur consistently in all instances of negative VOT-values, and was not so explicit that it could be considered a true addition of a distinct nasal consonant. One reason for the occurrence of this perceptually discernable nasal quality during the pre-voicing interval, could be that the subjects were merely a little late with velopharyngeal closure in those cases. However, based on the previously described theory of Rothenberg (1968), it can also be argued that these, being instances of nasal airflow, could have been one of his proposed 'special' articulatory mechanisms, with the goal of sustaining transglottal air pressure drop so that vocal fold oscillation (initiation and maintenance of voicing) could occur. Although much younger children and a different language

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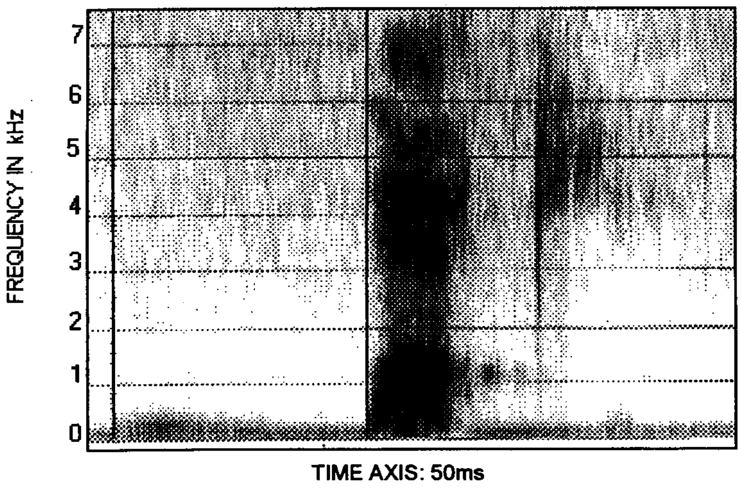
were studied, Allen (1985) in a VOT-study of French children aged 1;9 to 2;8 years, interestingly also found that voiced targets were sometimes preceded by a nasal or vowel segment. Allen (1985) believed that this was a strategy of the children to avoid producing pre-voiced stops, which he postulated was articulatory more difficult to produce. Again, the proposed possibilities are merely hypothetical. Discussion of this issue is limited by the lack of comparable data, and the small amount of subjects used in this study.



Nasal quality b a ki

FIGURE 4.4: PRODUCTION OF [baki] BY S9, INDICATING NASAL QUALITY RESULTING IN A VERY NEGATIVE VOT (-384ms)

4.8.2. DESCRIPTION AND DISCUSSION OF VOT-RESULTS OF WORDS STARTING WITH VOICELESS STOPS [p], [t] AND [k] (i.e. [p̲aki], [t̲asə], [t̲ɔpi], [t̲ək] AND [k̲atə])

The VOT-results obtained for voiceless stops [p], [t] and [k] will be discussed with reference to the data in Table 4.27 (where VOT-values for words starting with these sounds were pooled together) and Figure 4.5, which visually illustrates the minimum, mean and maximum VOT-values for the different age groups and material (data from Table 4.27).

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Results from Table 4.27 and Figure 4.5 indicated that all the age groups obtained *mean VOT's* for voiceless stops between +11ms and +17ms. These VOT-values obtained by the age groups for voiceless stops were significantly lower than those usually reported for English. Zlatin and Koenigsknecht (1976) found that for the English language, a greater concentration of VOT's for labial voiceless stops occurred between +50ms and +100ms, with VOT's for alveolar and velar voiceless stops occurring between +60 and +100ms.

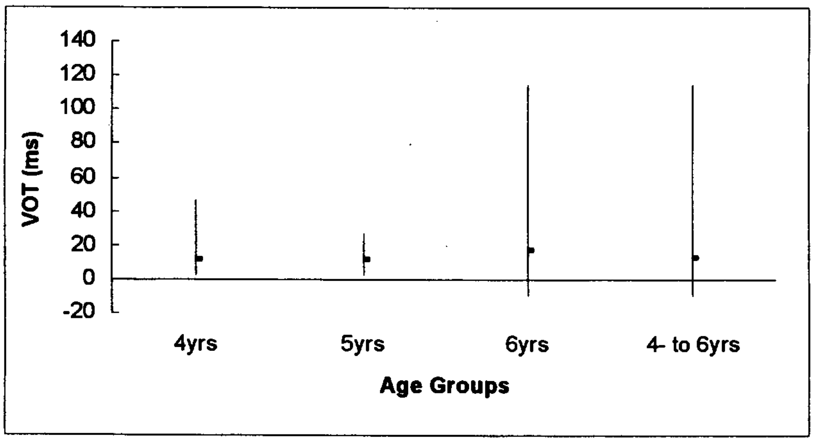

FIGURE 4.5: AGE GROUP VOT-DATA (i.e. MINIMUM, MEAN, MAXIMUM) FOR VOICELESS INITIAL STOPS [p], [t] AND [k]

In the present study *mean VOT-values* of +40ms or above never occurred for voiceless initial stops (see Table 4.26), indicating that Afrikaans-speaking children's mean VOT's for *voiceless stops* thus seem to fall into what is generally referred to in VOT-research as the *short voicing-lag range* (i.e. 0 to +39ms), as opposed to English VOT-values which generally extend into the *long voicing-lag range* (Kewley-Port & Preston,1974; Zlatin & Koenigsknecht, 1976). (More detailed definitions of terminology can be found in Table 2.5).

This big difference in results can be a direct effect of language differences, since voiceless stops in English are aspirated while Afrikaans stops generally are not. Indeed, the values obtained by the subjects in this study for voiceless stops compare much better with the range reported for Dutch adults by Lisker and Abramson (1964) namely 0 to +35ms. Results thus indicated that VOT-values for voiceless stops in Afrikaans-speaking children aged 4;0 to 6;7 years differed considerably from those of English children, most probably due to the absence of aspiration in the Afrikaans-language, with Afrikaans mean VOT-values being concentrated in the short-lag voicing range (i.e. 0 to +39ms). (It is emphasized that all the subjects produced perceptually distinct voiceless stops).

The VOT-data for voiceless stops further indicated that the subjects produced longer VOT-values for velar stop [k] than for labial and alveolar stops [p] and [t] (Table 4.26). The subjects as a group obtained the following percentages of *mean VOT-values* above +20ms for the different stops: [p]= 0%, [t]=10%, and [k]=50% (calculated from data in Table 4.26). Results thus indicated that Afrikaans children aged 4;0 to 6;7 years showed a progression of later mean voicing-lag times from the most *anterior* point of constriction in the vocal tract (labial), to the *velar* position, which is in agreement with findings for English adults (Lisker & Abramson,1964; Zlatin,1974; Baken, 1987) and children (Zlatin & Koenigs-knecht,1976).

Further, all the age groups displayed slightly higher (i.e. more positive) *mean* VOT values for *voiceless* stops than for *voiced* stops (Table 4.27). Data in Table 4.26 indicated that only one subject (S9, a six-year-old) showed one small negative mean VOT-value (i.e. –4ms) for voiceless stops.

4.8.3. DESCRIPTION AND DISCUSSION OF VOT-RESULTS FOR VOICED STOP [b] IN CLUSTER [bl] (i.e. [blɔki])

The VOT-results obtained for voiced stop [b] in cluster [bl] will be discussed with reference to the data in Table 4.27 and in Figure 4.6 which visually illustrates the minimum, mean and maximum VOT-values for the different age groups and material (data from Table 4.27).

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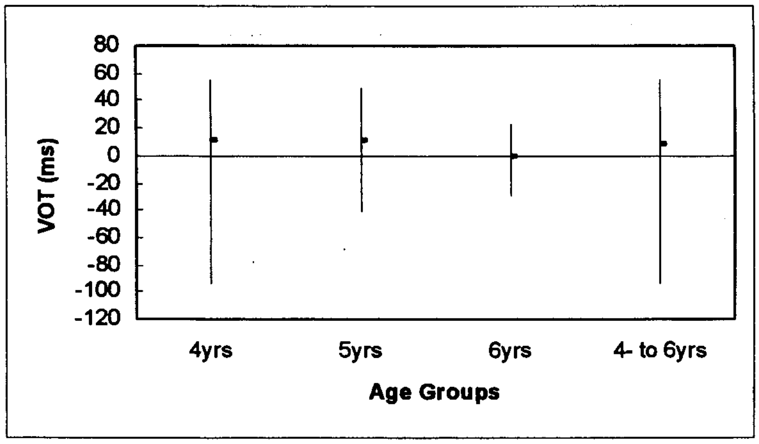

FIGURE 4.6: AGE GROUP VOT-DATA (i.e. MINIMUM, MEAN, MAXIMUM) FOR VOICED STOP [b] IN CLUSTER [bl])

Results indicated more or less similar performance across age groups, although the six-year-olds again tended to produce more negative mean VOT's than the other age groups, similar as to what was observed with the previous results for voiced word-initial stops. Analysis of the ***mean*** VOT-data in Table 4.26 indicated that voicing lead occurred in 70% of the mean VOT's of the subjects for voiced stop [b] in cluster [bl], and 70% of the mean VOT's for voiced word-initial stop [b] (Table 4.28). However, when the data in Table 4.27 are considered, it is evident that the mean VOT's for [b] in [bl] were slightly higher (more positive values) than for word-initial [b].

Klatt (1975) also reported VOT-values slightly higher for the [b] in [bl] (cluster context) than in a word-initial context, but offered no explanations for this finding. Baken (1987:377) noted that "...in stressed single-word utterances a VOT less than +25ms or so can be said to signal an English voiced plosive. Longer VOT's indicate a voiceless phoneme." 20% of the mean VOT-values reported for [b] in [bl] in this study (Table 4.26) were found to be +25ms or above (as opposed to 0% in the case of [b] in the word-initial context), but these values were displayed by only S1 (mean: +26ms) and S4 (mean: +32ms). The stops in all these cluster productions were clearly perceived as voiced though. It is possible that these few instances of higher positive VOT-values could have been the result of more profound instances of *aspiration* which were observed in these subjects' spectrograms. Aspiration could thus have extended the voicing lag.

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4.8.4. DESCRIPTION AND DISCUSSION OF VOT-RESULTS FOR VOICELESS STOP [k] IN CLUSTERS [kl] AND [kn] (i.e. [klɔki] AND [knəbəl])

The VOT-results obtained for voiceless [k] in clusters [kl] and [kn] will be discussed with reference to the data in Table 4.27 (results for these two words were pooled together) and Figure 4.7, which visually illustrates the minimum and maximum VOT-values for the different age groups and material (data from Table 4.27).

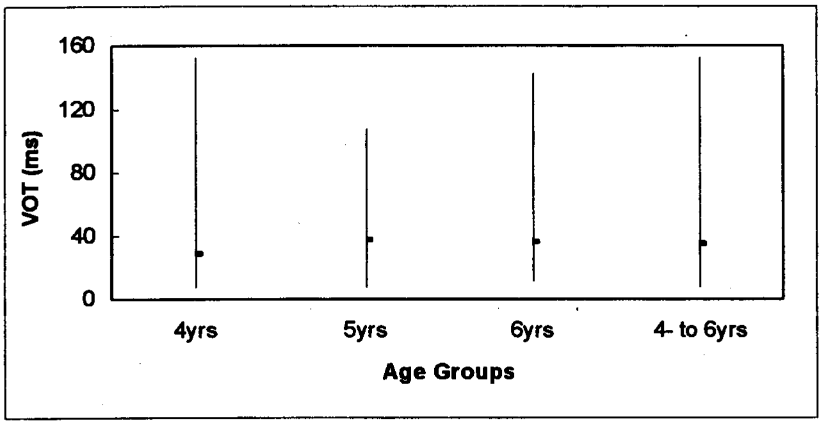

FIGURE 4.7: AGE GROUP VOT-DATA (i.e. MINIMUM, MEAN, MAXIMUM) FOR VOICELESS STOP [k] IN CLUSTERS [kl] AND [kn]

VOT-results obtained for voiceless stop [k] in clusters [kl] and [kn] indicated that all age groups displayed much higher *mean VOT's* for these sound in clusters than in word initial position (Table 4.27). Mean VOT-values of +40ms and above (thus ranging into what is theoretically referred to as the *long* voicing-lag range) occurred in 25% of the means for the clustered context, as opposed to 0% of the means of the word-initial context (Table 4.26). Klatt (1975) also reported VOT-values slightly higher for the [k] in clustered context [kl] than for [k] in a word-initial contexts. Aspiration was heard and noticed on the spectrogram in most of the higher (i.e. more positive) VOT's in this study, which could have caused these instances of high positive VOT's, but it is unclear why it occurred.

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An interesting observation concerning cluster production was that the subjects as a group produced [knəbəl] as [kənəbəl] in 29% of all their productions. This vowel could be perceived and occasionally also be observed on the spectrogram (in terms of vowel formants). The insertion of this epenthetic vowel did not occur in any of the other clusters (or spontaneous speech samples), but was also observed in cluster production, as previously discussed. According to Hawkins (1984) this type of modification of adult clusters implies a lack of coarticulation between the two consonants. It can be argued that the [kn]-cluster, which involves moving the tongue from a *velar* position to an *alveolar* position, and simultaneously opening the velopharyngeal port to create a nasal air stream, may be articulatory speaking more complex to coordinate than [bl] and [kl], where oral airstream and velopharyngeal closure are maintained in the transition. It can be hypothesized that general timing for cluster-[kn] may not yet be so mature or adult-like in some normal children aged 4;0 to 6;7 years of age. When the VOT-data were compared it was found that the [k] in [knəbəl] showed the longest overall mean VOT of all three clusters (Table 4.26).

Unfortunately all of the cluster results are very difficult to interpret due to the lack of comparable acoustic VOT-data. Byrd (1996) has recently emphasized the complexity of cluster production by stating that "...consonant sequences are of special interest in creating models of speech production, as often many demands are concurrently placed on an individual articulatory structure, the tongue. The tongue must execute these demands in a short period of time, and the consonants are not discretely articulated Consonant cluster timing is likely to be variable and subject to myriad influences interacting in complex ways." Extensive data is needed before any further interpretations can be made.

4.8.5. DESCRIPTION OF VOT-RESULTS FOR COMBINED VOICED STOP CONTEXTS (i.e. WORD-INITIAL AND CLUSTER) AND COMBINED VOICELESS STOP CONTEXTS (i.e. WORD-INITIAL AND CLUSTERS)

The VOT-data for *voiced stop material* (i.e. data for word-initial and cluster voiced contexts combined) indicated that the subjects as a group displayed mean VOT's for all voiced stops ranging from -97ms to +12ms and voicing lead in 26% of the mean VOT-values reported for voiced stops (Table 4.29). The *six-year-olds* showed the overall most instances of mean voicing lead for voiced stop contexts (i.e. 80%) and the five-year-olds the least (i.e. 4%.).

TABLE 4.29: SUMMARY OF VOT-DATA FOR COMBINED VOICED STOP CONTEXTS AND COMBINED VOICELESS STOP CONTEXTS

COMBINED VOT-DATA FOR VOICED STOPS ***(i.e. data for word-initial [b], [d] and cluster context [bl] combined)***		
Overall range of individual VOT's for the group (4;0 to 6;7 year-olds):	-384ms to +55ms	
Mean VOT-range for the group (4;0 to 6;7 year-olds:	-97ms to +12ms	
Overall percentages of *mean voicing lead* in voiced stops:	***Subjects as a group (4;0 to 6;7 year-olds)***	26%
	4-year-olds:	27%
	5-year-olds	4%
	6-year-olds	80%
COMBINED VOT-DATA FOR VOICELESS STOPS ***(i.e. data for word-initial [p], [t], [k] and cluster contexts [kn] and [kl] combined)***		
Overall range of individual VOT's for the group (4;0 to 6;7 year-olds):	-10ms to +152ms	
Mean VOT-range for the group (4;0 to 6;7 year-olds:	+11ms to +37ms	
Overall percentages of *mean long-voicing lag* (i.e. VOT's of +40ms and above) for voiceless stops:	***Subjects as a group (4;0 to 6;7 year-olds)***	7%
	4-year-olds:	5%
	5-year-olds	9%
	6-year-olds	7%

The VOT-data for *voiceless stop material* (i.e. data for word-initial and cluster voiceless contexts combined) indicated that the subjects as a group displayed mean VOT's for all voiceless stops ranging from +11ms to +37ms (Table 4.29). The subjects as a group displayed overall instances of *mean long voicing-lag* (i.e. VOT's of +40ms and above) for 7% of the voiceless stop material and the age groups performed very similarly (Table 4.29).

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4.8.6. SUMMARY OF VOT-RESULTS

Voicing lead occurred more frequently in the mean VOT-values of six-year-olds. Six-year-olds thus evidenced more of an ability to produce the complex articulatory movements and inter-articulator synchronization associated with the production of negative VOT's than five and four-year-olds. Results seem to confirm the hypothesis that the production of short voicing-lag VOT's may be easier to accomplish than articulatory movements of either stops with voicing lead or long voicing-lag. The subjects' mean VOT-values for *voiced stops* fell into either the *voicing lead* or *short-voicing lag* category (i.e. 0 to +39ms) for English.

Mean VOT-values for *voiceless stops* fell mostly in the short voicing-lag category (i.e. 0 to +39ms) while values in the long voicing-lag range (i.e. +40ms and above) seldom occurred (only in some cluster contexts). Results further showed a progression of later mean voicing-lag times from the most *anterior* point of constriction in the vocal tract (labial), to the most posterior (velar) position. Subjects occasionally inserted a schwa-vowel in productions of the word [knəbəl], which may indicate that production of this cluster in terms of inter-articulator synchronization may be more difficult for some normal children to accomplish than for others. It can be hypothesized that schwa-insertion may allow more time for inter-articulator synchronization and coordination.

Due to the lack of comparable normative data about the development of VOT in voiced and voiceless stops in Afrikaans and the small number of subjects used in this study, all interpretations must be considered tentatively. Extensive longitudinal and cross-sectional research of both younger and older children, as well as adults are needed to expand on this preliminary observations regarding VOT-development of Afrikaans stops. However, basic normative information regarding VOT-characteristics (i.e. inter-articulator synchronization) of normal children between 4;0 and 6;7 years were obtained, to which speech motor control skills such as inter-articulator synchronization and coordination of children with developmental speech disorders can be compared with.

4.9. DESCRIPTION AND DISCUSSION OF RESULTS FOR SUB-AIM EIGHT: FIRST SYLLABLE DURATION (FSD) IN WORDS OF INCREASING LENGTH

The goal of this sub-aim was to investigate acoustically if normal, Afrikaans-speaking children in the age range 4;0 to 7;0 years make any adaptations in first-syllable duration (FSD) in imitated words of *increasing length* and if so, what the nature of these adaptations are.

The following terms will be used for the subsequent description and discussion of the results for sub-aim eight. *Word group* will refer to the three words of increasing length that were grouped together (see Table 3.8) e.g. word group one (Wg1) consists of [pan], [panə] and [panəkuk]. *Length A* will be used to refer to the shortest word in every Wg (word group) e.g. [pan], *Length B* will refer to the second longest word e.g. [panə] and *Length C* will refer to the longest word in every word group e.g. [panəkuk].

Figure 4.8 visually illustrates the FSD-results of the subjects as a group for the three word lengths. FSD-data of words of the same length were pooled together. Figure 4.9 depicts the same pooling of data but for the other three age groups (four, five and six-year-olds). Figures 4.10 and 4.11 depict the mean FSD and FSD-standard deviation data for the subjects as a group for each word group.

4.9.1. GENERAL DESCRIPTION AND DISCUSSION OF FSD-RESULTS

The data from Figures 4.8 and 4.9 indicated that for all the age groups the longest mean FSD (first syllable duration) occurred in the *shortest* words, and that the shortest mean FSD occurred in the *longest* words (observed in 70% of all the word groups). Results thus indicated a *general trend of a decrease in FSD with increased word length.*

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This is surprising when taking into account that the words in the different word groups were elicited randomly and not successively (in which instance learning could have played a role in decreased duration).

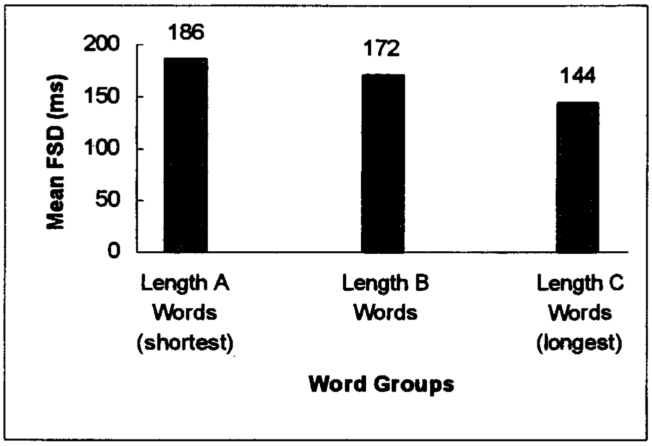

FIGURE 4.8: MEAN FIRST-SYLLABLE DURATION (FSD) OBTAINED FOR THE SUBJECTS AS A GROUP FOR THE DIFFERENT WORD LENGTHS

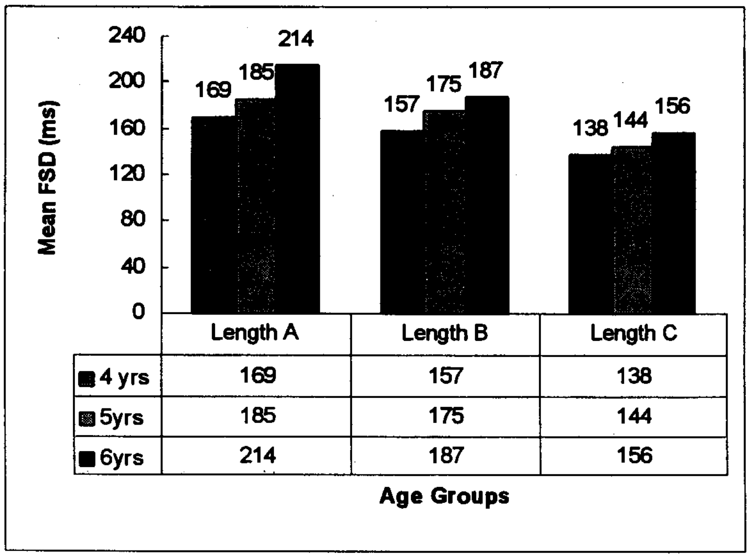

FIGURE 4.9: MEAN FIRST-SYLLABLE DURATION (FSD) OBTAINED BY THE AGE GROUPS FOR THE DIFFERENT WORD LENGTHS

Results thus indicated that Afrikaans-speaking children aged 4;0 to 6;7 years adapted FSD to word length by *decreasing* FSD as word length of the material increased. The results for the subjects as a group showed that only 30% of the

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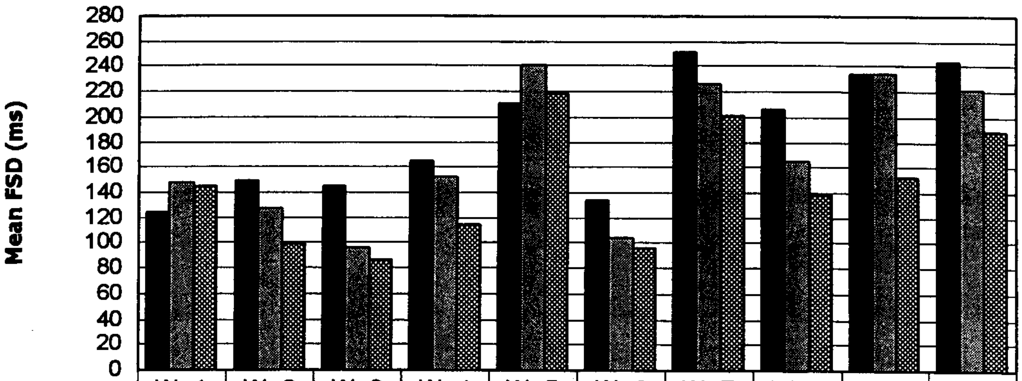
word groups did not show this general trend (Figure 4.10). Individual subject results also indicated that this effect was not consistently present in every word group for all the subjects. Individual trends in performance occurred frequently and it was very difficult to identify any age-related trends (except for the mean FSD-values, which will be discussed later).

The general decrease in FSD that was observed with an increase in word length was not present in Wg1 (tel/telling/telefoon), Wg5 (blom/blomme/blombakke), and Wg9 (man/manne/mannetjie) (Figure 4.10). It was noticed that in these words, (as well as in other individual cases where subjects did not display the overall trend), word length *B* frequently had the longest duration. Figures 4.12, 4.13 and 4.14 display the individual FSD-results for these three word groups.



	Wg 1	Wg 2	Wg 3	Wg 4	Wg 5	Wg 6	Wg 7	Wg 8	Wg 9	Wg 10
Length A	123.6	149.2	144.3	164.4	210.5	133.6	251.9	205.6	234.4	243.9
Length B	148.6	127.2	96.3	152.5	240.9	103.8	226.6	164.7	233.8	221.2
Length C	145.5	98.9	87.2	115.6	219.2	96.2	200.8	137.7	153.3	189.1

Word Groups

FIGURE 4.10: MEAN FIRST-SYLLABLE DURATION (FSD) DISPLAYED BY THE SUBJECTS AS A GROUP FOR THE DIFFERENT WORD GROUPS

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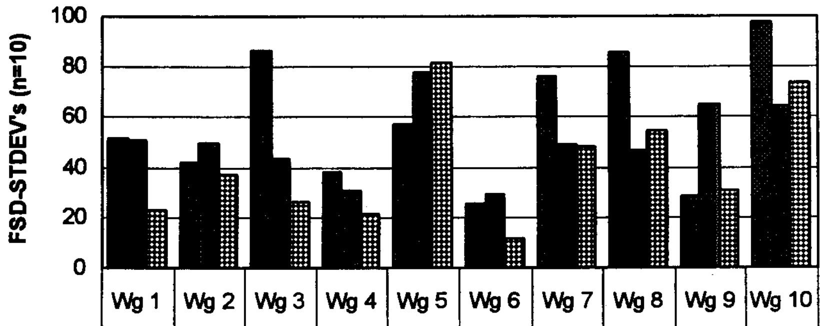

	Wg 1	Wg 2	Wg 3	Wg 4	Wg 5	Wg 6	Wg 7	Wg 8	Wg 9	Wg 10
tel bak doek pan blom kop knop lip man vin	51.4	41.7	86.8	38.4	56.8	25.4	76	86.1	28.3	97.7
telling bakkie doeke panne blomme koppies knoppe lippe manne vinne	50.8	49.7	44	30.7	77.5	29.5	49	46.7	65	64.3
telefoon bakkery doeksakke pannekoek blombakke koppietjie	22.9	37.3	26.5	21.7	81.7	12	48.4	54.5	31.3	73.7

Word Groups

FIGURE 4.11: FIRST-SYLLABLE DURATION (FSD) STANDARD DEVIATIONS FOR THE SUBJECTS AS A GROUP (CALCULATED FOR THE DIFFERENT WORD GROUPS)

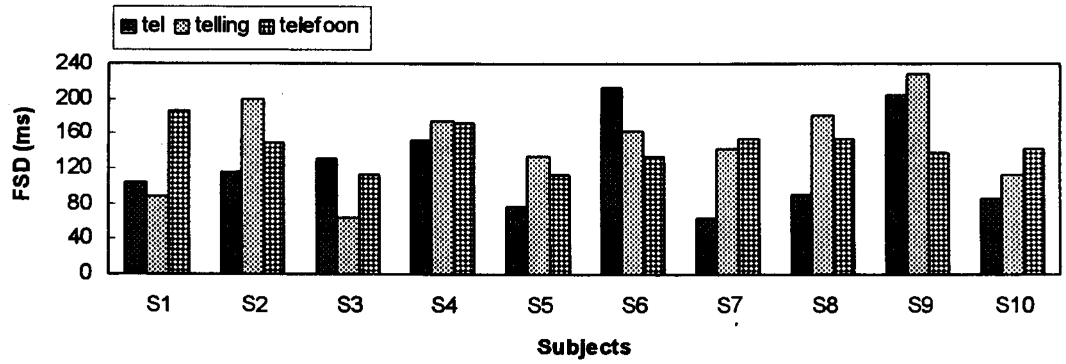

FIGURE 4.12: INDIVIDUAL FSD-RESULTS FOR WORD GROUP ONE

It is very difficult to explain why these words did not show the generally observed effect, and why word length B occasionally was the longest in those cases. The manner in which these words' length increased from length A to length B to length C did not appear to differ linguistically much from the pattern of increasing length in the other words. In fact, in several other cases where word

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length was increased by addition of a sound like [ə] or [i] (similar to Wg5 and 9), FSD generally did decrease when length increased (e.g. doek/doeke/doeksakke). The only observable difference was in the case of Wg1 (i.e. tel/telling/telefoon). This was the only word group where word length was increased by adding the Afrikaans suffix '-ing' (which changes the word "tel" from 'n verb to a noun) and not the plural suffix [ə]/[s] or the diminutive suffix [i]. It can be proposed that some phonological or semantic variable could have played a role. However, it is not clear exactly how, since one subject (S6) still showed the effect of a decrease in FSD with increasing word length for this word group.

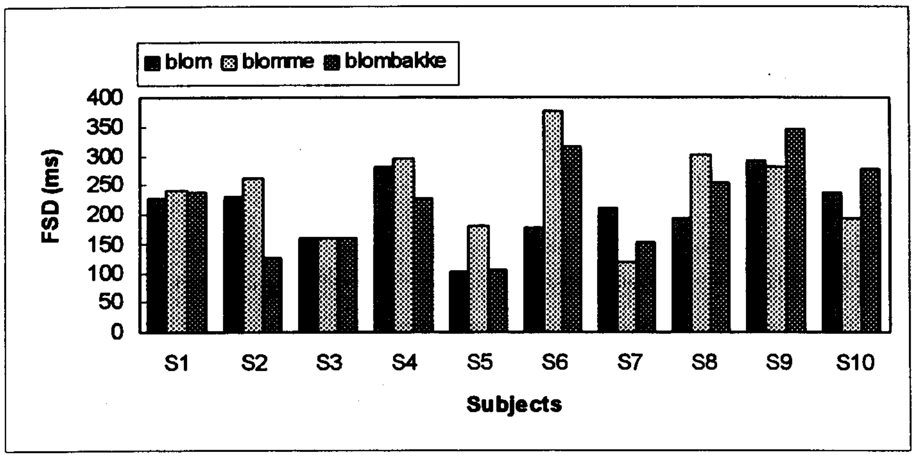

FIGURE 4.13: INDIVIDUAL FSD-RESULTS FOR WORD GROUP FIVE

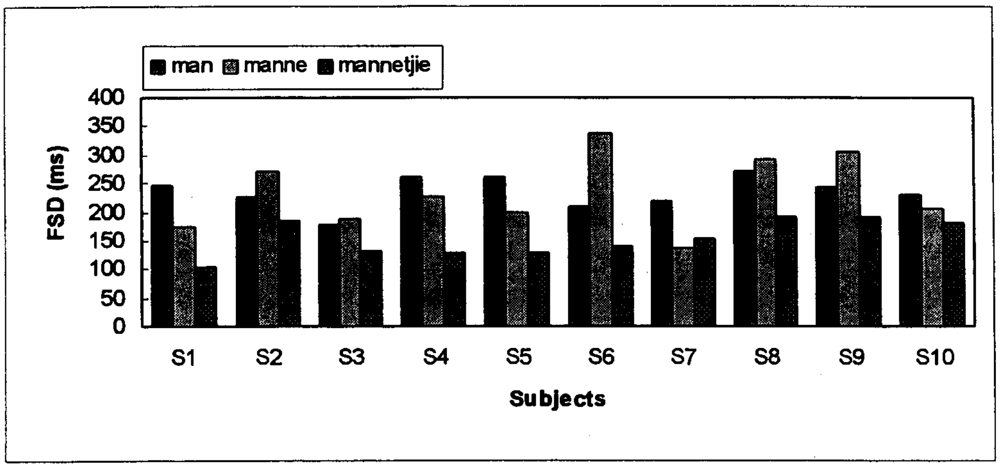

FIGURE 4.14: INDIVIDUAL FSD-RESULTS FOR WORD GROUP NINE

In addition, no pattern that could help explain the results was identified in the sequence or manner of presentation of the material. The same random order and manner of presentation were maintained for all the subjects.

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Due to the limited number of research in this area for both the English and Afrikaans languages, it can only be concluded at this stage that a combination of unknown linguistic/phonologic, phonetic or other unidentified factors may have contributed to the observed effects. These results indicate the need for more research in this area.

Results further indicated that for Wg1 (tel/telling/telefoon), S7 and S10 even showed an *increase in FSD with increased word length,* which was opposite to the general trend. S3 also displayed this slightly in Wg3 (doek/doeke/doeksakke) but no other subjects showed it in any other word groups. A contributing factor to the occurrence of this effect in S3's results, was the fact that he produced [duk] with such a fast transition from [d] to [k], that almost no vowel formants were seen on the spectrogram. Again it is uncertain why S7 and S10 showed this effect in their FSD's. The low frequency of occurrence of an *increase* in *FSD* with *increased word length* may indicate it to be an exception to the rule, or just very individual trends in performance.

An unexpected result in FSD was the fact that the *oldest* children (six-year-olds) had the *longest* mean FSD followed by the five-year-olds and finally the four-year-olds with the shortest mean FSD (see Figure 4.9). These results thus indicated an *increase* in FSD with *increased age*. This occurred for all three word lengths and is unexpected in the light of the fact that researched conclusively indicated that segmental duration usually tend to decrease with increased age. In this study too for example, in spite of some individual exceptions, the six-year-olds showed a tendency to show the shortest mean FVD-. A possible explanation for this unexpected tendency may be the fact that S9 and S10's spectrograms frequently displayed instances of pre-voicing in material starting with stops, in contrast with the younger subjects who seldom did. As a result of the measurement procedure (which included these instances of pre-voicing in the FSD-value), S9 and S10's first-syllable duration values were thus automatically longer in duration that those of the other subjects. Figure 4.15 illustrates one such instance (i.e. S10 producing [duk] with pre-voicing).

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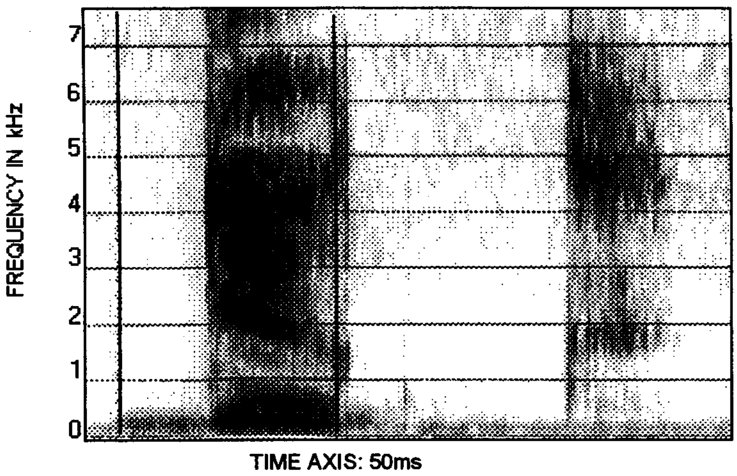

d u k

FIGURE 4.15: EXAMPLE OF PRE-VOICING DISPLAYED BY S10, RESULTING IN A LONG FSD-VALUE OF 190ms FOR FIRST SYLLABLE [du] in THE TARGET WORD [duk]

4.9.2. DESCRIPTION AND DISCUSSION OF INDIVIDUAL TRENDS IN FSD

In addition to the discussed group trends, the following observations were made spectrographically and perceptually regarding occasional individual productions of the material. These observations may contribute to a better understanding of at least some of the results (e.g. longer FSD in some words) and in general of aspects present in normal children's sensorimotor control of FSD. First, longer FSD-values were sometimes the result of *lengthening of a consonant or vowel* e.g. [tæl] was sometimes characterized by a vocalic transition e.g. [tihæl]. Words starting with sound combinations were frequently produced by the lengthening of one sound in the cluster e.g. [l] in [bl......ɔki], lengthening of the whole first syllable e.g. [blɔ....mə]. This also occasionally occurred in words starting with continuants e.g. [l] in [ləp] and fricatives [f] in [f...ən] or [f...ənəx]. *Aspiration* was another factor that was observed spectrographically and contributed to longer FSD e.g. [k^{h}nɔp] (knop). Interestingly, Hawkins (1973:208) regarded increased aspiration of fricatives in a cluster as the result of an "...effort to reduce the articulatory load...". It's uncertain if the same speculation can be made of results in this study. *Epenthesis* of schwa vowel [ə] occurred in two word groups namely

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Wg5 and Wg7, with the clusters [bl] and [kn] which also caused increased FSD e.g. [kənɔp] (a spectrographic example of this can be seen in Figures 3.6). A final contribution to increased FSD was *negative voice onset time* (pre-voicing) in words starting with voiced plosives, which was especially evident in the older children's data (i.e. S8, S9 and S10) and has already been discussed previously (see Figure 4.15).

4.9.3. GENERAL DISCUSSION OF FSD-RESULTS

Although no studies directly related to all these results could be identified, results of Lindblom (1968) indicated that in the utterances of mature speakers, both consonant duration and vowel duration are decreased as the overall length of an utterance is increased. Schwartz (1972) found a similar phenomenon and interpreted it as evidence that a speaker scans ahead to appraise the length of the utterance and uses this information to determine the amount of time he may devote to the articulation of individual sounds. DiSimoni (1974:b) repeated Schwartz (1972)'s experiment with children aged three, six, and nine-years-old and found the phoneme duration conditioning effects to be present in the speech of six and nine-year-old children but not in three-year-olds. He concluded that his experiment showed "...aspects of the chronologic sequence of development of durational control systems in children..." and suggested the possibility of a "...hierarchy of coarticulatory functions..." (DiSimoni,1974:b: 1354). House (1961) found that the duration of a stem word decreases as the length of the utterance increases, which Lehiste (1970) explained as rule-governed phonological behavior. Unfortunately not much is presently known about rule-governed variables involved in segmental duration in the Afrikaans language.

It is known that several factors can influence sensorimotor speech timing control, although details regarding these processes are not yet completely determined. Picket in Glasson (1984:87) summarized general lengthening and shortening effects as follows: "(1) the greater the number of sub-units in speech, the shorter is each sub-unit (2) each sub-unit is shorter up to a minimum duration of compressibility; and (3) successive sub-units have a greater effect than antecedent

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sub-units". However, specific details of such effects on children's sensorimotor timing control patterns are too few to represent a standard (Glasson,1984).

Due to the lack of related research findings in this area for both English and Afrikaans-speaking children, it can only be concluded at this stage that a combination of linguistic, segmental and suprasegmental variables may have contributed to the observed FSD results. This may range from factors such as the characteristics of the phonetic environment of the words and the sound following the first syllable, and stress patterns (although unlikely, since stress was on the first syllable of all the words), to a range of unknown and possibly yet unidentified phonetic, linguistic and other factors. These findings can be regarded as further indication of the very complex nature of sensorimotor speech control.

4.10. CONCLUSION

In this chapter the results for the different sub-aims were described and discussed with reference to existing research findings. General normative data for speech motor development were presented in the areas of non-speech oral movements, non-speech oral diadochokinesis, speech diadochokinesis, cluster production, word syllable structure, aspects of first-vowel duration, variability of first-vowel duration, voice onset time in stops, and first-syllable duration in words of increasing length. A basic, normative database for a variety of speech motor developmental parameters in normal, Afrikaans-speaking children in the clinically important age range of 4;0 to 6;7 years, has thus been established, to which the same speech motor skills in children with developmental speech disorders can be compared with.

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CHAPTER 5

EVALUATION OF THE STUDY, SUMMARY OF RESULTS AND CONCLUSIVE DISCUSSION

5.1. INTRODUCTION

In this chapter the research method of the study will firstly be evaluated in terms of strengths and weaknesses. A summary of the main findings for each sub-aim will then be provided, together with a discussion of its major clinical and theoretical implications. General aspects of speech motor development that emerged from the findings of this and previous studies that need to be considered in future research and clinical assessment, will then be discussed. This will be followed by recommendations for future research.

5.2. EVALUATION OF THE RESEARCH METHOD

The research method has strengths in the following areas:

-The study's method was theoretically based on the characteristics of speech as a fine-sensorimotor skill and a theoretical framework of sensorimotor speech control (i.e. Van der Merwe,1997). These clear theoretical underpinnings are considered to be a strength of the study, since it laid the foundation for a clear focus on sensorimotor (non-linguistic) processes of speech production, served to define terminology, to identify, formulate and motivate sub-aims, and to direct the construction of an assessment battery that addressed a variety of parameters of sensorimotor speech control development. It also provided a framework of interpretation of results.

-Since the test battery focused on basic aspects of sensorimotor speech control, with all material compilation and data elicitation procedures described in detail,

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it will be relatively easy to adapt and translate it to other South African languages.

-The multi-subject case-study research design, together with the implementation of 'methodological triangulation' (i.e. using both quantitative and qualitative description of data) were effective in establishing a normative information basis regarding the 'normal range of performance' possible for normal children aged 4;0 to 6;7 years (mean age: 5;2 years) on these assessment tasks, and also to identify individual trends in performance.

-The data elicitation and recording procedures were found to be efficient in eliciting good co-operation from the subjects and to ensure reliable samples. These procedures are expected to have good clinical assessment potential.

-The rating scales compiled for data-analysis for sub-aims one, two and three were effective in rating and describing performance and can be clinically used to expand traditional assessments of these areas.

The following <u>limitations</u> can be identified in the method:

-The absence of an Afrikaans-speaking adult control group is a limitation, since its inclusion might have led to more direct comparison of adult and child performance on sensorimotor speech control tasks, and thus possibly to more extensive explanation and interpretation of the children's results. Overall it might also have provided additional information regarding the performance of normal Afrikaans-speaking adults on these tasks.

-More subjects per age group and an equal number of subjects per age group (i.e. four-year-olds, five-year-olds, six-year-olds) may have provided more extensive normative information and may have allowed for more complex statistical analysis procedures (e.g. direct age group comparisons).

-It may be difficult to perform the assessment battery on children younger than four years, or on children with developmental speech disorders (DSD) with concomitant language, attention, or auditory processing problems, due to the fact that a certain amount of co-operation and concentration is required.

-Clinically, it may be difficult for therapists to obtain access to instrumentation such as spectrographic analysis, implying that the results of sub-aims seven, eight and nine presently have more application value for future research (e.g.

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comparative studies of sensorimotor speech control characteristics of normal children and those with suspected DSD's), than for clinical usage.

-On the other hand, implementation of more sophisticated instrumental analysis procedures such as kinematic or electromyographic measurements might have enabled the assessment of additional and possibly more detailed aspects of sensorimotor speech control and its development, although this would have decreased clinical applicability even more.

5.3. SUMMARY OF FINDINGS

The main aim of this study was to collect general, normative information regarding certain sensorimotor speech control abilities of normal, Afrikaans-speaking children. This aim was reached since a variety of basic, previously non-existing information for Afrikaans-speaking children were gathered regarding different aspects of sensorimotor speech control for normal children aged 4;0 to 6;7 years (mean age: 5;2 years). In addition, basic qualitative assessment of non-speech oral movements (NSOM), non-speech diadchokinesis (NSO-DDK) and speech diadochokinesis (S-DDK), were expanded in the form of compiled Rating Scales (used to perceptually rate performance). A basic sensorimotor speech assessment battery, together with basic normative information were thus established, to which the performance of Afrikaans-speaking children with (DSD) in the age range 4;0 to 6;7 years can be compared with in the future. A summary of the findings for each sub-aim, together with clinical and theoretical implications of these results are presented in Table 5.1.

TABLE 5.1: SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim One: **Voluntary non-speech oral movements (NSOM):** *Isolated oral movements (I-OM), *Two-sequence oral movements (2S-OM) *Three-sequence oral movements (3S-OM)	*All subjects were capable of voluntary execution of all the individual components of all target movements in all three sections (indicating the absence of oral apraxia in these normal subjects as expected). *However, most of the subjects' performance on these tasks were not completely adult-like, since: -Only four (40%) subjects (S6,S7,S8,S9) scored perfect ratings for I-OM -Only three (30%) subjects (S3,S6,S8) scored perfect ratings for 2S-OM -Only two (20%) subjects (S4,S6) scored perfect ratings for 3S-OM -Only one subject (10%) (S6:5;4 yrs) scored perfect ratings in all three sections *The *types* of errors that occurred however, were only minor in nature and restricted to: *Associated movements*: (Only a., b. and c.-ratings occurred for this rating scale Category I) I-OM: lifting chin and tilting head with target movement (TM) 1.3. (*lick an ice cream*) were displayed by five (50%) of the subjects. 2S-OM: mandible movements in tongue lateralization tasks (TM 2.2. and 2.3) displayed by five (50%) of the subjects 3S-OM: five (50%) of the subjects displayed backwards head-tilting when trying to touch their noses with their tongue (TM 3.2.), which may be considered a result of effort rather than being a true associated movement. *Accuracy errors*: (Only a., c., d., and f.-ratings occurred for this rating scale Category II) I-OM: five (50%) subjects displayed either inaccurate or incorrect movements with upward tongue licking movements. This was characterized by circular/in-out-movements, or by resting the tongue on the lower lip during execution.	*The fact that the majority of these normal children did not show perfect execution in all three these sections, implies that the execution of NSOM may *not yet be completely adult-like* for all normal children in this age range, and may continue to develop after 6;7 years of age. *The fact that one subject did manage to get perfect ratings for all the sections, implies that some normal children can show adult-like performance at this age, indicating possible *individual trends* in performance. * Children in this age range can still be expected to show minor *associated movements* when performing tongue *lateralization* tasks and upward tongue licking movements. * The second part of TM 3.2. (i.e. "then touch your nose with your tongue") should be changed to a more achievable task such as "touch your upper lip with your tongue" in future assessments, due to the relative impossibility of this task. * Children in this age range can still display minor *accuracy errors* when performing upward tongue licking movements, but the majority of children can be expected to perform these non-speech tasks with good accuracy. * Normal children in this age range can be expected to *sequence* these two and three-sequence oral movements well. However, four-year-olds may need key words for 2S-OM, and four to six-year-olds may need key words for 3S-OM, in order to aid the auditory recall of commands.

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TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim One **Voluntary non-speech oral movements (NSOM):** *(-continued)*	2S-OM: three (30%) subjects displayed either inaccurate (i.e. inadequate touching of lip corners/sweeping tongue over bottom lip) or incorrect movements (i.e. in-out, or inside instead of outside mouth) for tongue lateralization tasks (TM.2.2 and 2.3), indicating that the majority of subjects did not experience accuracy problems for 2S-OM. 3S-OM: only two (20%) subjects displayed error ratings, indicating that the majority of subjects did not experience accuracy problems for 3-SOM *Sequencing errors:* (Only a., c., d., and f.-error ratings occurred for this rating scale Category III) 2S-OM: only the two (20%) youngest subjects (four-year-olds) displayed problems. 3S-OM: only three subjects (30%) obtained correct sequencing without any key words provided, while only one subject's performance did not improve with the provision of key words, indicating that auditory memory problems may have contributed to sequencing errors. * No general age-related trends were observed, except for the fact that the two youngest subjects display auditory-memory problems with 2S-OM in addition to 3S-OM, while the older children managed correct sequencing without key words for 2S-OM.	*It may be appropriate to incorporate key words when using these tasks for assessment purposes in clinical settings, since children with DSD may also have accompanying auditory processing problems, which can further hamper auditory recall. *A traditional pass/fail system or the mere reporting of diadochokinetic rates (i.e. quantitative analysis) when assessing children's performance on NSO-DDK tasks may not be adequate, and need to be expanded by *qualitative* descriptions and analysis of occurring error types. This may lead to more information regarding symptom patterns in DSD.

TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Two: **Non-speech oral diadochokinesis (NSO-DDK):** -Tongue lateralization -Tongue in-and-out -Lips pout-stretch -Jaw open-close	* Only one subject (S7:5;4 yrs) scored perfect ratings on all four target movements. The type of errors that occurred though were only minor in nature and restricted to the following: *Associated Movements:* (Only a., b., c., and d.-ratings occurred for this rating scale Category I). Five (50%) subjects displayed associated movements of body and/or articulators for TM (target movement) 1 (*tongue lateralization outside mouth*) and TM 2 (*tongue in and out the mouth*), with only two (20%) displaying some associated movements for TM 3 (*lips pout-stretch*) and TM 4 (*jaw open-close*). A too fast execution rate led to an increase in associated movements *Accuracy Errors*: (Only a., d. and f-ratings occurred for this rating scale Category I.). Four (40%) subjects scored perfect ratings on accuracy while the rest of the subjects only displayed occasional error ratings indicating that the subjects generally were capable to execute these tasks with good accuracy. It was observed that a too fast execution rate decreased accuracy *Sequencing Errors*: (Only a., c, and f.-ratings occurred for this rating scale Category III.) Five (50%) subjects scored perfect ratings on sequencing, while the rest of the subjects only displayed occasional error ratings, indicating that the subjects generally were capable of executing these tasks with good sequencing. *Continuity:* (Only a, b, and d-ratings occurred for this rating scale category IV.). Five (50%) subjects scored perfect ratings on continuity, while the rest of the subjects only displayed occasional error ratings, indicating that the subjects generally were capable of executing these tasks with good continuity.	*The fact that the majority of these normal children did not show perfect execution for all four target movements, implies that NSO-DDK may *not yet be completely adult-like* for all children in this age range. *Since one subject did manage to obtain perfect ratings for all the sections, it can be deducted that some normal children can show more adult-like performance at this age. This indicates possible *individual trends* in speech motor development in this area. *Children in this age range can be expected to exhibit associated movements in *tongue lateralization* and tongue *in-out* movement tasks, but generally seem able to execute these tasks with only *occasional* and minor errors of accuracy, sequencing and continuity. *The mere reporting of diadochokinetic rates (i.e. quantitative analysis) when assessing children's performance on S-DDK tasks, needs to be expanded by *qualitative* descriptions and analysis of occurring error types in order to expand the applicability of such testing. This may for example, lead to expanded information regarding symptom patterns in DSD.

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TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Three: **Speech Diadochokinesis (S-DDK):** -velar DDK: [dənə] -glottal DDK: [pəbə] -tongue DDK: [tə] & [kə] -lip DDK: [pə] -combined DDK in two-place articulation syllable strings: [pəkə], [təkə], [kəpə] and [kətə]) -combined DDK in three-place articulation syllable strings: [pətəkə], [kətəpə] and [təpəkə]	*<u>Normative Diadochokinetic Rate (DDR) Data</u>: *(See Tables 4.5, 4.6, 4.7 and 4.8 for detailed normative data)* .The elicitation procedure described in the method (Chapter 3) was effective for children this age. DDR's increased as the syllable length of the material increased. - Range of DDR's for the subjects as a <u>*group*</u> *(measured in number of repetitions per second)*: [tə]: 2.8 to 5 [pə]: 3 to 4.8 [kə]: 2.8 to 5.2 [pəbə]: 1 to 1.6 *(based on accurate productions)* [dənə]: 1.6 to 2.4 [pəkə]: 1.6 to 2.8 [təkə]: 1.4 to 2.6 [kəpə]: 1 to 2.6 [kətə]: 1.4 to 2 [pətəkə]: 1 to 1.8 [kətəpə]: 0.8 to 1.4 [təpəkə]: 0.8 to 1.2 -No age-related trends could be identified for four, five and six-year-olds and very individual trends in performance occurred. DDR-differences between material of the same structure category were small. * <u>*Perceptual Results:*</u> *(Based on percentage correct-PC-scores and rating scale analysis)*. -Very few errors occurred with tongue and lip-DDK-tasks (CV-syllables). The lowest overall PC-score was obtained for glottal DDK-task [pəbə] with many voicing (II.d) and substitution errors (IV.c) occurring. Some subjects reduced their execution rate in a possible attempt to increase accuracy, but not all subjects displayed this tendency. It also did not always result in increased accuracy. Very few errors occurred for the other two-place DDK-tasks (CVCV-syllables). In some children fast execution rates resulted in reduced accuracy, while others maintained good accuracy in spite of fast execution rates. -For three-place DDK-tasks the subjects displayed the highest PC-scores for [pətəkə], followed by [kətəpə] and the lowest PC-score for [təpəkə]. Error patterns for all DDK-task were very individualized and no error rating dominated the results *(see Tables 4.10, 4.11, 4.12, 4.13, and 4.14 for error type details)*. No associated movements occurred in any of the S-DDK tasks (in contrast with the subjects' performance on NSO-DDK tasks).	*The fact that no clear *age-related trends* were identified and that individual trends in performance occurred, implies that it may be more appropriate to use DDR-results of the subjects as a <u>*group*</u> for normative, assessment purposes in a clinical setting. For example, when a five-year-old child's DDR's are assessed, it should be determined whether they fall outside the normal <u>*range*</u> reported for 4;0 to 6;7 year-old normal children as a group, rather than to compare the child's performance to norms for his/her *specific* age group (i.e. five-year-olds) or to mean *DDR's*. *Glottal DDK-tasks seem to be difficult to accomplish for some normal children in this age range and voicing and substitution errors can occur. It's possible that glottal and three-place syllable sequences place more demands on sensorimotor speech planning in terms of rate, accuracy, continuity and sound structure. *Some normal children in this age range may apply a *reduction in rate of execution* as a natural, *compensatory strategy* to accomplish more complex articulatory movement sequences, although not all such attempts may result in increased accuracy. It will be interesting to determine how children with DSD handle these tasks (e.g. if they employ the same strategies as normal children and how 'successful' it is). *Both *rate* and *accuracy* should be considered when children's performance on more difficult S-DDK-tasks are evaluated, although the exact relationship between these two concepts is not yet established and appears to be complex. It can be deducted that the traditional practice of reporting DDR-values only in assessments *(i.e. quantitative analysis)* without reference to *accuracy* or occurring *error types (i.e.qualitative analysis)*, yields limited information about speech motor abilities. For example, it is possible that a child with fast DDR's but with little accuracy in production, has 'poorer' speech motor performance than a child with slower DDR's but who displays more accuracy.

TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Four: **Cluster production:** Initial and final consonant clusters in isolation	*Subjects generally obtained higher PC-scores for initial (i.e. 84%) than for final clusters (i.e. 79%). * 79% of errors with initial clusters were the result of schwa-vowel insertion and the other 21% errors were of a mixed type. *For final clusters 47% of the errors were the result of an addition of the syllable [hə] in front of the cluster, 45% were the result of a schwa-vowel insertion and 8% of errors were of a mixed type. *None of these error types occurred in the subjects' spontaneous speech sample.	*Some normal children in this age range may still find it difficult to produce some clusters in isolation. The planning and sequencing of consecutive motor goals for *final* cluster combinations appear to be more complex for the majority of children than for *initial* clusters. *Results may indicate that the occurrence of *schwa-vowel insertion* and addition of the syllable [hə] in clusters produced in isolation, can be expec-ted from normal children in this age range. It possibly is a compensato-ry strategy to allow more time for articulatory transitioning and sequencing of motor goals from one consonant to another, thus a way of handling higher articulatory demands. *The fact that the subjects were able to produce words starting and en-ding with clusters accurately in spontaneous speech, may indicate that the production of a cluster in isolation (which can be argued to be a "non-linguistic' context), places different *demands* (i.e. maybe greater) on speech motor planning than the production of a cluster in spontaneously produced words. *The results raise some interesting questions regarding contextual effects on sensorimotor speech planning of clusters, which are yet unanswered. It also provides some additional *motivation* for determining a child's productive repertoire for producing initial and final clusters in isolation. Such assessment may yield some information regarding aspects of sensorimotor planning, programming and execution such as *coordination* and *sequencing* of speech movements, without having added linguistic and phonological factors influencing performance. Byrd (1996:209) has argued that the study of consonant sequence production is of special importance in understanding "articulatory organization" and thus in creating models of speech production.

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TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Four: **Cluster production:** *(-continued)*	*(See previous page)*	*It will further be interesting to determine if children with DSD use the same 'strategies' (e.g. schwa-vowel and syllable [hə] insertion) to possibly assist the production of these sequences, and/or if they show errors different from these normal children. Until more research has been conducted in terms of cluster production in isolation, it seems warranted to include such testing in a speech motor control assessment battery.
Sub-Aim Five: **Word syllable structure:**	*The subjects produced a total of *163* different word syllable structure combinations. Of these structures *18* (11%) occurred at least once in the spontaneous speech samples of each subject, while 145 (89%) occurred at least once in some subject's sample.	*Normal children of this age display sensorimotor speech skills that are developed to such an extent that they can plan, program and execute a wide variety and intricate sequence of *consecutive motor goals* in spontaneous speech, resulting in sometimes very lengthy and creative word structures. *It can be hypothesized that normal-speaking children's sensorimotor speech control systems are capable to convert complex phonological sequences, which were linguistically planned (selected and sequenced) during the linguistic-symbolic phase of speech production, to a code that can be handled by the speech motor system (Van der Merwe, 1997). They can thus be said to be able to "...plan the consecutive movements necessary to fulfill the spatial and temporal goals..." by "...identifying the different motor goals for each phoneme..." and by sequentially organizing the "...movements that are necessary to produce the different sounds in the planned unit..." (Van der Merwe, 1997:11). *Further, they can specify articulator-specific motor goals such as lip rounding, jaw depression, glottal closure, or lifting of the tongue tip, and plan inter-articulator synchronization for each phoneme in the utterance (Van der Merwe, 1997).

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YUNIBESITHI YA PRETORIA

TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Five: **Word syllable structure:** *(-continued)*	*(See previous page)*	* Using word structure analysis in the assessment of sensorimotor speech control is still in need of more development. It is recognized that at this level of assessment, language and sensorimotor aspects of speech production are complex and interrelated, and that it can be very difficult, and possibly artificial, to separate the two concepts. As Hawkins (1984:355) put it: "As a motor skill, speech is learned in accordance with laws governing the acquisition of any other motor skill, although the unique relationship between speech and other linguistic and non-linguistic systems means that its acquisition may also have unique aspects.". It is for example clear that *linguistic factors* such as a child's vocabulary, syntactic, morphological and phonological skills also play a role in the type and length of word structures displayed. Yet, it's hypothesized that word syllable structure analysis also has the potential to give at least *some* indication of *the level of sensorimotor control* a child has mastered, in addition to being a reflection of linguistic skills. This may be especially be the case when additional *qualitative* analysis of word syllable structure takes place (e.g. in terms of possible error types or preferences), and when results are interpreted within the context of a variety of data obtained from a test battery combining the assessment of linguistic-symbolic planning skills and sensorimotor speech control (i.e. non-linguistic skills).
Sub-Aim Six: **Segmental duration in repeated utterances** a) First-vowel Duration (FVD):	*The *mean FVD* of the subjects ranged from 98ms to 169ms (thus a wide range) as calculated across target words. * A direct *increase* in mean FVD with *increased age* was only observed in two target words (out of a possible thirteen).	*Although results imply that a tendency may exist for six-year-olds to generally show faster FVD's than five and four-year-olds, it appears as if developmental FVD-changes do *not* necessarily occur on a *yearly* basis for four, five and six-year-old normal children. It is possible that the 4;0 to 6;7 year period is not characterized by major developmental changes in FVD. Rather, based on the *wide range* of values that these normal children have displayed, very individual FVD-performance may be prevalent for this age range.

TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Six: **Segmental duration in repeated utterances** a) First-vowel Duration (FVD): *(-continued)*	*In spite of no consistent age-related differences for the rest of the material, a tendency did exist for the *oldest* age group (six-year-olds) to show the *shortest* mean FVD most often. However, the youngest age group (four-year-olds) did not obtain the longest mean FVD most often. * A tendency for individual rather than age-related performance was thus present. For example, the shortest overall mean FVD was displayed by a five-year-old (S7:5;4 yrs) but the two longest overall FVD's were also displayed by two five-year-olds (S8 and S4). *A contextual effect that emerged from the data was that duration of a vowel preceded by a *voiced plosive* were longer than the duration of the same vowel preceded by a *voiceless* plosive (difference ranged from 4ms to 36ms, depending on material).	*Due to the wide range of FVD-values that may occur for this age range, it is important in future research and/or clinical assessments that *clustering* of results for subjects in this age range according to age in years is carefully approached. Secondly, a child with suspected DSD's performance should be compared with the *range of FVD-values* displayed by these normal subjects as a group, rather than with subjects of exactly the same age. *Results seem to provide some evidence for theories suggesting that normal children do not necessarily 'mature' on the *same schedule* with regard to the same aspects of sensorimotor speech control (Smith and Kenney, 1998), and that different children may develop at different *rates* (Von Hofsten,1989). **Preceding consonantal voicing* appears to affect FVD, implying that it may be a contextual influence worth studying in future studies of linguistic and phonetic influences on FVD.
Sub-Aim Six: **Segmental duration in repeated utterances** *(-continued)* b) Variability of FVD	*Subjects displayed FVD-values ranging from 39ms to 263ms across all utterances and target words (a range of 224), indicating great inter- and intra-subject variability in FVD. *Age-related decreases in variability with increased age did not occur. However, a tendency was found for the oldest subjects (six-year-olds) to obtain the *least* variability (i.e. smallest CfV) the most, and for the five-year-olds to display the *highest CfV* (i.e. most variability) the most. *Very individual trends in performance occurred, with children of the same age sometimes showing contrasting results. High intra-individual variability also occurred. *The *most* variability in FVD (i.e. the highest CfV) was displayed by the subject who had the *shortest* mean FVD across target words (S7-5;4yrs) and the *least* variability by S9 (6;1yrs) who had the fourth highest mean FVD.	* Inter- and intra-subject variability for FVD seem to be high for children in this age range. Normal children can thus be expected to show very individual FVD-values, which can vary over a large range for different repetitions and different target words. *Clear age-related differences do *not* seem to be present for FVD in this age range and children of the same age may perform differently. * Results imply that in assessment, a child with a suspected developmental speech disorder's performance should be compared with the *range* of FVD-values displayed by the subjects as a group, rather than with subjects of exactly the same age, since this may allow for 'normal' individual variation.

UNIVERSITEIT VAN PRETORIA
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TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Six: **Segmental duration in repeated utterances** b) Variability of FVD *(-continued)*	*(See previous page)*	*Based on the theory that skilled motor performance is marked by a faster execution rate and less variability (e.g. Bruner,1973), subjects with shorter FVD's will be expected to show less variability in FVD than subjects with longer FVD's. However, the fact that the subject in this study with the *shortest* FVD displayed the *most* variability, may rather be evidence in favor of hypotheses that segmental duration and variability are not closely related, that these concepts possibly reflect *different* aspects of sensorimotor speech development and further, may *not* develop *in tandem* (e.g. Smith, 1992; Smith,1994).
Sub-Aim Seven: **Voice onset time (VOT)**	**Minimum, maximum and mean VOT-values for the subjects as a group:* -*word-initial* voiced stops: -384ms to +30ms (*mean*: -14ms) -voiced stops in *clusters*: -94ms to +55ms (*mean*:+9ms) -*combined voiced contexts mean VOT range:* -97ms to +12ms -*word-initial* voiceless stops: -10 to +114ms (*mean*: +13ms) -voiceless stops in *clusters*: +8ms to +152ms (*mean*: +35ms) -combined voiceless contexts mean *VOT-range:* +11ms to +37ms * *Normative results for voiced stops:* -S9 and S10 (six-year-olds) displayed *voicing leads* in almost all of their productions of words starting with voiced stops, unlike any of the younger subjects. *Mean voicing leads* occurred in 88% of the six-year-olds', in 0% of the five-year-olds', and in 25% of the four-year-olds' productions. The subjects as a group displayed 25% mean voicing leads. -Long intervals of pre-voicing displayed by the six-year-olds were sometimes marked by a perceptually discernable nasal quality which can be interpreted as either the result of a late velopharyngeal closure, or as a 'special' articulatory mechanism with the goal of sustaining transglottal air pressure drop so that vocal fold initiation can occur. -The subjects displayed slightly more positive (i.e. higher) mean VOT's for voiced stops in *clusters* than for word-initial voiced stops.	*Normal children younger than six years have a tendency to display a greater percentage of *positive* VOT's (i.e. voicing-lag) than negative VOT's (i.e. voicing lead) in initial *voiced stop productions*. They may be expected to seldom exhibit negative VOT's. Six-year-olds on the other hand may produce negative VOT's more often. *Based on the physiology of stop consonant production, it can be hypothesized that the production of a *voicing lead* (i.e. negative VOT's) may require more careful timing between glottal and supra-glottal articulators and thus more *complex inter-articulator synchronization* than the production of positive VOT's between 0 and +39ms (short voicing-lag). This implies that normal Afrikaans-speaking six-year-olds display the possibly more complex interarticulator-synchronization associated with the production of *voicing lead* VOT's, with greater frequency than four and five-year-olds. This possibly indicates more *mature* sensorimotor voice onset time control abilities for six-year-olds.

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TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
<u>Sub-Aim Seven:</u> **Voice onset time (VOT):** *(-continued)*	* *<u>Normative results for voiceless stops:</u>* -*Mean* VOT's of all age groups for voiceless *word-initial* stops fell between +11ms and +17ms (i.e. short-lag voicing lag range), probably due to the small amount of aspiration involved in Afrikaans voiceless plosive production. Mean VOT-values displayed by these subjects for voiceless stops corresponded with the range reported for Dutch rather than for English. A progression of later mean VOT-lag times from the most anterior point of constriction in the vocal tract (labial) to the most posterior (velar) position was present. *The subjects displayed slightly higher mean VOT-values for [k] in a cluster than in word-initial context. * *<u>Normative results for combined contexts:</u>* -Overall percentage of *mean voicing lead* displayed in <u>voiced</u> stop contexts (word-initial and cluster context combined) by the subjects as a group: 26% -Overall percentage of *mean long voicing-lag* displayed for <u>voiceless</u> stop contexts (word-initial and cluster contexts combined) by the subjects as a group: 7% * Epenthesis of vowel [ə] in the word [knəbəl] occurred in 29% of all the subjects' productions, possibly indicating a lack of coarticulation between the two elements of the cluster. No problems with words containing this cluster were found in the subjects' spontaneous speech samples, but was also observed in isolated cluster production.	*Unlike English-speaking children, Afrikaans-speaking children do not show VOT-values for *voiceless word-initial stops* in the long-lag voicing range (i.e. +40ms and above), although higher VOT's may occur for voiceless stops in *cluster* contexts. This is a linguistic difference in VOT between these languages. *Some normal children may show schwa-vowel epenthesis in repeated utterances of the Afrikaans-word [knəbəl], possibly indicating that this cluster is articulatory speaking more *complex to coordinate* than the other clusters. It is possible that schwa-insertion may allow more time for inter-articulator synchronization and coordination. * It still has to be determined why schwa-epenthesis for [kn] occurred in cluster production in isolation, and also occasionally in repeated utterances of the word [knəbəl], but was not present in the subjects' spontaneous speech samples. Several questions regarding contextual influences on VOT were raised by the findings of this study. *It will be interesting to compare inter-articulator synchronization abilities of children with DSD in the same age range, with the performance of these normal children, in order to determine if they exhibit the same performance trends in VOT-control.
<u>Sub-Aim Eight:</u> **First-syllable duration (FSD) in words of increasing length:**	* For all age groups the *longest* mean FSD occurred in the *shortest* word length context, while the *shortest* mean FSD occurred in the *longest* word length context, indicating a general *<u>decrease</u> in FSD* with *<u>increased</u>* word length. *Only 30% of the word groups did not show a direct decline in FSD with increased length (i.e. Wg1, Wg5 and Wg9).	*Normal children can be expected to generally adapt FSD to word length by *<u>decreasing</u> FSD* as *word length <u>increased</u>*, except for the three word groups mentioned. *It is possible that some yet unidentified linguistic or phonetic variable/s could have played a role in the fact that three words in the material did not show this effect, implying that the *<u>nature</u>* of the material have to be considered a contextual variable in studies of FSD.

TABLE 5.1 (-CONTINUED): SUMMARY AND IMPLICATIONS OF RESULTS

SUB-AIMS	SUMMARY OF RESULTS FOR NORMAL CHILDREN AGED 4;0 to 6;7 years	THEORETICAL AND CLINICAL IMPLICATIONS OF RESULTS
Sub-Aim Eight: **First-syllable duration (FSD) in words of increasing length:** *(-continued)*	* Longer FSD-values in some instances were the result of consonant, vowel or whole first-syllable lengthening, vowel addition, epenthesis of schwa vowel [ə] between two cluster elements, lengthening of one cluster element, aspiration and/or pre-voicing (i.e. negative VOT's, only noticed for the six-year-olds). *An unexpected finding was that the oldest subjects (six-year-olds) had the *longest* mean FSD for all three word groups, followed by the five-year-olds and finally the four-year-olds with the shortest mean FSD. This indicated an increase in FSD with increased age. However, this could have been mostly the result of occasional, individual instances of pre-voicing (as those described in VOT-results), and instances of aspiration that was evident in the spectrograms of productions of S9 and S10.	*The fact that normal children in this age range generally do adapt FSD to the length of the utterance, may indicate that they are capable of some degree of speech motor planning such *as scanning ahead* to appraise the length of the utterance, and then to use the information to determine the time that can be devoted to articulation of sounds and syllables (Schwartz,1972). *It is thus possible that children in this age range exhibit *context sensitivity* (Van der Merwe, 1997) in terms of FSD. It will be interesting to determine if younger children and children with DSD of the same age, display the same tendencies. *FSD-results need to be analyzed both ***quantitatively*** (i.e. mean durational aspects) and ***qualitatively*** (i.e. perceptual errors such as epenthesis or spectrographically discernable processes such as pre-voicing/aspiration), in order to determine all possible variables contributing to results.

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

5.4. CONCLUSIVE DISCUSSION OF SPEECH MOTOR DEVELOPMENT

Collectively, the body of information regarding normal children's speech motor development indicates a *gradual increase* in various aspects of sensorimotor speech control from birth to puberty. However, specific details regarding this developmental process are only beginning to be uncovered. Currently we lack descriptions of general *stages* of speech motor development from birth to puberty. The *range* of normal speech motor performance that can be expected from normal children at different ages for different *parameters* of sensorimotor control also has not yet been fully documented. Further, the exact influence of a variety of *factors* (i.e. linguistic aspects, auditory perceptual skills, neuro-physiological maturational factors) on sensorimotor speech control development is undetermined. In addition to being limited, current normative data regarding speech motor development are also very *diverse* in terms of methodical aspects such as parameters studied, ages of subjects and instrumentation used.

As result of all these factors a standard *set of parameters* for clinical assessment of sensorimotor speech control development has not been established. This has a negative effect on assessment of speech motor skills of children in the clinically important age range of four to seven years, ages when children are frequently referred for speech-language assessments due to suspected developmental speech disorders (DSD's). Presently, it is difficult to clinically identify and specify potential isolated or accompanying problems with *non-linguistic* processes of speech production such as sensorimotor speech planning, programming and execution that may contribute to the symptom patterns of children with DSD. The *complex* nature of the speech production process and the resulting *hypothetical status* of most current theories of normal speech production and its sensorimotor control and development, further contribute to the problem with the identification of assessment parameters.

In spite of the current lack of specific details regarding speech motor development, the diverse nature of research in this field, and the hypothetical

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nature of theories and models of speech production and speech motor control, certain conclusive principles regarding the general development of sensorimotor speech control are indicated by the results of this and previous studies. By considering these general aspects in future research and clinical assessments, the effectiveness of assessment and treatment of possible sensorimotor speech problems in the pre-school years and other ages will ultimately be expanded.

Firstly, it appears as if a *wide range* of what can be considered 'normal' performance is possible regarding sensorimotor speech control aspects for children of the same age (i.e. the trend of high inter-subject variability). This implies that researchers have to be sensitive for *individual* trends in normal performance, and further, should *document and describe* such trends extensively rather than to consider it exceptional and not worth further investigation. The traditional focus in research regarding speech motor development on *group* findings and tendencies thus has to shift to also include more documentation and descriptions of *individual* performance. Smith and Kenney (1998:96) recently cautioned that our basic understanding of speech motor development represents a somewhat "...generalized or idealized descriptions of changes found to occur across groups of children of different ages...", since "...group data reveal 'average' performance across many subjects, but they do not reflect the developmental patterns of individual children". Von Hofsten (1989:952-953) similarly warned that "...pooling data for groups of individuals of the same age will 'smear' the developmental function, hide important transitions, and make it look smooth and uneventful.".

Descriptions of normal *individual variation* and *individual characteristics* of speech motor performance, in addition to general group tendencies, will lead to the establishment of a more reliable normative database in terms of the normal range of performance possible for a certain speech parameter. With the normal range of performance for a specific parameter available, the speech motor skills of children with DSD can be assessed more adequately and reliably. In addition, longitudinal studies of individual children's performance across time which is presently very scarce, will also supplement and enhance the overall understanding of speech motor development (Smith & Kenney,1998). Such

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YUNIBESITHI YA PRETORIA

combined and complementary approaches to the study of sensorimotor speech development will lead to more comprehensive knowledge of this phenomenon.

In addition, the need for more extensive descriptions of individual trends in performance implies that *quantitative* analysis of performance on different speech motor tasks, need to be supplemented with *qualitative* analysis of performance on the same tasks (e.g. description of error patterns by the application of rating scales). Hawkins (1984:367) wrote in terms of speech motor development that "...a reasonable first step in understanding underlying processes is to describe what is observed.". Qualitative analysis allows for such description. Although it may be a lengthy process to compile such extensive and specific information, eventually such data may assist in determining for example, whether a given child displays a mere *delay* in aspects of speech motor development (e.g. by displaying behavior of a normal but much *younger* child), or whether the displayed behavior is an indication of some *impairment* in sensorimotor speech control (e.g. by displaying *different* behavior not usually exhibited by normal children of the same age, neither by normal younger children). Differential diagnosis of DSD will also be ultimately enhanced.

A third aspect that needs to be considered in sensorimotor control development is that *different parameters* yield different perspectives on the processes of normal sensorimotor speech control. Integrated assessment of several different measures of speech production may thus lead to better interpretations of results, and ultimately to the identification of the most appropriate set of parameters for clinical assessment of speech motor development. Further, researchers and clinicians have to be sensitive to the possibility that results from recent studies have suggested that different sensorimotor speech parameters may not necessarily change at the same rate or within the same time frame as a child develops (e.g. Nittrouer,1993;1995; Smith & Goffman,1998; Smith & Kenney,1998). This is in line with trends in general motor development. Nittrouer (1993) for example, inferred that jaw and tongue speech gestures have distinctive developmental time courses, with jaw movements maturing earlier than tongue movements. Von Hofsten (1989) emphasized an important principle of general motor development which is that the general rate of development is different for different children

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

and that one child may develop quickly at certain ages and slower at others. Smith and Kenney (1998:104) for example found that a "...child who demonstrates quite adult-like values in certain parameters may still be considered quite non-adult-like in other aspects of speech production.", implying that not all sensorimotor speech skills mature on the same schedule for a given child. The rate and change for individual parameters and/or the periods during which such changes may occur, may differ considerably among subjects and across ages. This emphasizes the complex nature of speech motor development and the necessity for many investigations of the development of a variety of parameters of sensorimotor speech control in children of all ages. Such an approach will serve to establish a body of information regarding the normal *range* of performance children can show for different parameters at different ages.

The issue regarding the possible diverse development of different parameters and in different children, further implies that a child's speech motor developmental status should not be assessed or judged based on one measurement only. A child may have no problems with one particular parameter, while still exhibiting sensorimotor control problems of a different nature than the parameter measured. Hawkins (1984:343) cautioned that "...there may be no changes in the parameter being measured, but some other relevant parameter may be changing.". A variety of sensorimotor speech control aspects thus need to be assessed in order to identify all possible problems in a specific child.

5.5. RECOMMENDATIONS FOR FUTURE RESEARCH

The following specific recommendations for future research are made:

-The test battery can be translated to assess populations of *other* normal, South African children speaking *languages* such as English, Zulu and Northern-Sotho. Comparison of differences and similarities in performance may throw more light on linguistic influences on timing aspects of sensorimotor speech control (e.g. VOT and first-vowel duration).

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-More *advanced* methods of assessment can be considered for future studies of non-speech voluntary oral movements and non-speech diadochokinesis such as visuomotor tracking, measurements of strength and fatigability, or control of static position and isometric force, as to expand assessment of possible dysarthric involvement and sensorimotor control processes such as programming and execution of speech movements. Speech motor tasks can also be assessed with more sophisticated instruments such as kinematic, electromyographic and areodynamic measurements.

-Overall similarities and differences in performance aspects of *speech and non-speech tasks* can be compared in order to explore the nature of the relationship between sensorimotor speech and non-speech sensorimotor control.

-The relationship between *rate* and *accuracy* of performance in speech diadochokinesis tasks (especially in more demanding tasks such as glottal and three-place syllable sequences), can be further and more directly explored, in order to investigate how normal children and children with DSD's plan more demanding speech motor contexts (e.g. the nature of compensatory strategies).

-Cluster production in *different contexts* can be investigated further in normal and diagnostic populations. Contexts such as isolation, words and spontaneous speech or contexts of meaningfulness (i.e. a linguistic context) versus meaninglessness (i.e. more of a non-linguistic context) can be examined for differentially diagnostic purposes. Differences between initial and final cluster production and general phonetic influences involved in cluster production and error types (e.g. schwa-vowel insertion as a possible compensatory strategy), can be further examined to determine the influence of linguistic factors on speech motor development.

-The effect of *linguistic* aspects on first-vowel duration can be investigated more extensively (e.g. preceding consonantal voicing) in normal and diagnostic populations, by using different and more complex contexts.

-The effect of *increasing task demands* (i.e. longer and more complex material, increased speaking rate) on these different parameters of speech motor control can be studied, since it has been hypothesized that increasing task demands may have a greater impact on the speech motor processes of children than on those of adults (Smith & Goffman (1998).

-The whole test battery can be applied to children *with developmental speech disorders*. It is possible that when this speech motor development assessment battery is incorporated in a *complete test battery* that addresses all four stages of speech production (i.e. linguistic-symbolic planning aspects, speech motor planning, programming and execution), in addition to aspects such as hearing, auditory processing, and oro-facial and pharyngeal structure and functioning, it may assist with *differential diagnosis* in DSD. Although still hypothetical, performance characteristics may yield some indication of the *affected level* of speech production (e.g. linguistic-symbolic planning, sensorimotor planning, sensorimotor programming and sensorimotor execution), since different types of disorders may display dissimilar impairments on the variety of parameters. The *nature* of specific disorders may thus be more clearly indicated. Performance on the test battery may also have the potential to indicate whether a child's sensorimotor speech skills are *delayed* (immature) or *deviant* when compared with the performance of normal children of different ages. Similarly, comparison with normative data can also serve to identify different *degrees of impairment* or *delay* (i.e. severity). The following are hypothetical examples of how performance on the test battery may reflect *differentially diagnostic aspects* of sensorimotor speech control problems, which can be considered in future investigations:

- Theoretically, children with *phonological* planning problems but no *sensorimotor* planning problems may exhibit FVD-values in the range reported for their normal-speaking peers. Children with sensorimotor speech control problems (i.e. such as dysarthria or DAS) may show *longer* FVD-values than normal-speaking peers and children with phonological planning problems, due to impairments in the planning, programming and/or execution of motor goals, plans and programs. Further, performance such as FVD-lengthening in the absence of any dysarthric indications or generalized

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neurological pathology for example, may be differentially diagnostic of a speech motor planning impairment or delay. In addition, age-inappropriate token-to-token variability in FVD may be expected in children with speech planning problems, due to inconsistent temporal specifications of segmental duration and interarticulator-synchronization. Children with dysarthric impairment may tend to show more consistently lengthened FVD's (depending on the type of dysarthria).

- Children with *sensorimotor speech planning* problems may show different VOT-characteristics than children with phonological planning problems or normal children, since they may have major problems with *interarticulator-synchronization*. This may result in a greater frequency of voicing errors (i.e. distortions). Children with normal speech motor planning abilities but possible phonological planning impairments, may be capable of producing VOT-values similar to those of normal peers, while their voicing errors may be true voiced/voiceless substitutions (indicating a phonological selection error).
- Children with *sensorimotor speech planning* problems may show opposite performance trends than normal children in terms of the *adaptation* of first-syllable duration to words of increasing length. Based on the premise that longer words may place more *demands* on all aspects of speech motor planning (i.e. more core motor plan recall, increased coarticulation, interarticulator-synchronization etc.) and that contextual adaptations of FSD have to take place when word length increases, FSD's of these children may be expected to increase as word length increases. They may thus need more time to adjust temporal and spatial aspects of speech movements to the changing contexts than normal-speaking children. Children with phonological planning problems on the other hand, can possibly be expected to display FSD-trends very *similar* to their normal-speaking peers, since they may not have difficulty to adapt temporal aspects to the changing context.

5.6. CONCLUSION

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Researchers and clinicians need to be sensitive to the immense *complexity* of the speech production process and processes central to its control and development. It is crucial that findings are related to theories of speech production, in order to infer what children's behavior on different sensorimotor speech tasks imply about their sensorimotor speech control development and the normal speech production process in general. Further, the contributing influences of various factors need to be carefully considered when speech motor performance is assessed and interpreted and test batteries compiled. These include the complex interaction of a variety of factors such as linguistic aspects (e.g. phonological influences, suprasegmental aspects), personal-social factors (e.g. motivational aspects and personality traits which may affect performance), auditory-perceptual factors, neural factors (e.g. brain maturation), musculoskeletal factors (e.g. structural growth and tissue changes) and even cognitive aspects.

Our ultimate goal should be to develop cost-effective and clinically effective assessment tools by which speech motor development can be assessed and problems efficiently identified and treated. Only through continuing research of both normal and deviant speech production, can the most appropriate assessment variables be identified and assessment tasks and analysis guidelines be developed and refined. We are only standing on the brink of uncovering the mysteries of sensorimotor speech control and to reach our goal will require continuous and persistent research. But as Crary (1993:xiv) said: "If we do not experiment, criticize and change, the ultimate losers will be the children.".

5.7. SUMMARY

In this chapter the method of this study was evaluated. This was followed by a summary of the results and a discussion of their theoretical and clinical implications. Speech motor development was conclusively discussed in terms of aspects that need to be considered in future research and assessment. Finally, specific recommendations for future research were made.

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APPENDIX A (CONTINUED):

EXAMINATION OF THE CHILD'S ABILITY TO PLAN AND EXECUTE ISOLATED, TWO-SEQUENCE , AND THREE-SEQUENCE VOLUNTARY NON-SPEECH ORAL MOVEMENTS (NSOM)

Instructions: Use the Rating scale and rate all target movement/s by assigning *all* applicable alphabet numbers (behavior descriptions) in each category.

NAME OF CHILD: ____
DATE TESTED: __________ **DATE OF BIRTH:** __________
CHRONOLOGICAL AGE: ________

RATING SHEET FOR SUB-AIM ONE

TARGET MOVEMENT/S	CATEGORY		
	I. Associated Movements	*II. Accuracy of Individual Movements*	*III. Sequencing*
Target Isolated Oral Movements (1-OM)			
1.1. Blow candle			
1.2. Puff cheeks			
1.3. Lick ice cream			
Target Two-sequence Oral Movements (2S-OM)			
2.1. Kiss, cough			
2.2. Lips, tongue			
2.3. Cheeks, tongue			
Target Three-sequence oral movements (3S-OM)			
3.1. Lips, cheeks, tongue			
3.2. Kiss, nose candle			

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APPENDIX A: TEST/RECORDING AND RATING SHEETS FOR SUB-AIM ONE

EXAMINATION OF THE CHILD'S ABILITY TO PLAN AND EXECUTE ISOLATED, TWO-SEQUENCE, AND THREE-SEQUENCE VOLUNTARY NON-SPEECH ORAL MOVEMENTS (NSOM)

<u>INSTRUCTIONS</u>: ***For (IOM):*** Ask the child to execute each of the tasks by saying:"I want you to do this…(followed by the tasks in the table). ***For (2S-OM & 3S-OM):*** First instruct the child verbally to execute each task and then demonstrate it e.g. "I'm going to ask you to do different things with your mouth, cheeks, lips and tongue. First I will tell you what to do and then I will show you how to do it". Practice an example first until you are sure that the child understands what is expected e.g. "Bite your lip and stick out your tongue. Like this….(demonstrate). Now you try and do it". Provide key words during testing, if the child give any indication of forgetting the instructions (in order to assist auditory memory). Note the child's responses in the open spaces provided in the table.

NAME OF CHILD: ______________________________________
DATE TESTED: __________ DATE OF BIRTH: __________
CHRONOLOGICAL AGE: _______

<u>TEST/RECORDING SHEET FOR SUB-AIM ONE</u>

Target Isolated Oral Movements (I-OM)	Target Two-sequence Oral Movements (2S-OM)	Target Three-sequence Oral Movements (3S-OM)
1.1. "Show me how to blow out a candle".	**2.1. "Blow a kiss and cough".** *Key Words: "Kiss, cough"*	**3.1. "Pout (pucker) your lips, puff out your cheeks and stick out your tongue".** *Key Words: "Lips, cheeks, tongue"*
1.2. "Puff out your cheeks".	**2.2. "Pout (pucker) your lips & then touch your left and right lip corners fast with you tongue" (lateralize tongue outside mouth).** *Key Words: "Lips, tongue"*	
1.2. "Show me how you lick an ice cream".		**3.2. "Blow a kiss, try to touch your nose with your tongue and show me how to blow out a candle".** *Key Words: "Kiss, nose, candle"*
	2.3. "Puff out your cheeks and then touch your left and right lip corners fast with your tongue (lateralize tongue outside mouth). *Key Words: "Cheeks, tongue"*	

APPENDIX C: TEST/RECORDING/RATING SHEET FOR SUB-AIM THREE

EVALUATION OF SPEECH DIADOCHOKINESIS

INSTRUCTIONS: In order to maintain interest and to elicit a good measurable sample, a game-like procedure can be used with plastic animal figurines running a pretend race on a toy racing track. The child can be allowed to choose a contestant (animal) from a toy box (different animal for each target utterance). Explain to the child that the animal can only run in the race while he/she maintained the production of the target utterance. Ask the child to start producing the target utterance when you say "Go" ! A miniature stop sign can be put at the end of the toy racing track and it has to be explained to the child that he/she should continue production until the animal (manipulated by the examiner) reaches the stop sign. The examiner can time the productions with a wristwatch (using the second hand). Elicit eight seconds of productions in order to ensure that 5 full seconds of productions are available for analysis. Practice the procedure thoroughly with examples until you are convinced that the child comprehended the procedure. The following instructions can be used: "You are going to help each animal to complete the race. Each animal can only run while you say the word I tell you to say. Let's practice with the dog. Let's pretend I ask you to say 'mie-mie-mie-mie'. What do you have to say ? (allow time for the child to answer). That's right. When I say "begin" you have to start saying "mie-mie-mie" until I say stop. The dog will only run as long as you say mie-mie-mie. If you stop speaking, the dog will also stop running. Let's practice it now. Say 'mie' until I say stop. Begin !".Elicit the target syllables randomly (from the list provided) . If the child has trouble producing the target sequence, the examiner can model it twice. Note any problems or additional information of the child's production on the recording form. Make an audio-recording of the test for later analysis (to count the number of productions and to rate productions using the *Rating Scale for the Evaluation of Speech Diadochokinesis.*

NAME OF CHILD: ______________________ DATE TESTED: _________ DATE OF BIRTH: __________CHRONOLOGICAL AGE: _______

TARGET	TRANSCRIPTIONS OF ALL TRIALS PRODUCED IN 5 SECONDS	RATINGS FOR II. ASSOCIATED MOVEMENTS	RATINGS FOR III. ACCURACY	RATINGS FOR IV. SOUND STRUCTURE	OVERALL RATING FOR I. CONTINUITY
Velar Diadochokinesis					
	1.				
[dənə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				
	11.				
	12.				
	13.				
DDR: ____	14.				
	15.				

APPENDIX B: TEST/RECORDING/RATING SHEET FOR SUB-AIM TWO

EVALUATION OF NON-SPEECH ORAL DIADOCHOKINESIS (NSO-DDK) OF THE TONGUE, LIPS AND JAW

INSTRUCTIONS: Ask the child to execute each movement in the table after demonstrating it first by saying: "I'm going to ask you to do different things with your tongue, lips and jaw. First I will tell you what to do and then I will show you how to do it". Practice an example first e.g. "Bite your lip over and over again. Like this....(demonstrate). Now you do it until I say stop". Try to elicit a continuous production of the target movement for a period of at least 5 seconds. Proceed to the test items when it is apparent that the child understands the procedure completely. If necessary, the examiner can provide initial verbal keywords in order to facilitate production (see table). However, continue this for a limited time-period only, (about 3 repetitions), until it is clear that the child executed the command correctly (as this assistance may interfere with normal rhythm). Note the child's responses in the open spaces provided in the table and rate all applicable descriptions according to the *Rating Scale for the Evaluation of Non-speech Oral Diadochokinesis.*

NAME OF CHILD: ______________________________
DATE TESTED: ____________ **DATE OF BIRTH:** _________
CHRONOLOGICAL AGE: _________

TEST/RECORDING/RATING SHEET FOR SUB-AIM TWO

TARGET MOVEMENT	DESCRIPTION OF BEHAVIOR	RATINGS FOR I. (ASSOCIA-TED MOVE-MENTS)	RATINGS FOR II. (ACCURACY OF INDIVI-DUAL MOVE-MENTS)	RATINGS FOR III. (SEQUEN-CING)	RATINGS FOR IV. (CONTI-NUITY)
1. ***Tongue lateralization outside the mouth***: Ask the child to move his/her tongue repeatedly and as fast as possible from one lip corner to another outside mouth. *Key Words: "left-right"*					
2. ***Tongue in and out of mouth***: Ask the child to move his/her tongue repeatedly and as fast as possible in and out of the mouth. *Key Words: "in-out"*					
3. ***Lips pout-stretch***: Ask the child to pout and stretch the lips repeatedly and as fast as possible. *Key Words: "round-flat"*					
4. ***Jaw open-close***: Ask the child to open and close the mouth repeatedly and as fast as possible. *Key Words: "open-close"*					

APPENDIX C (-CONTINUED):

TARGET	TRANSCRIPTIONS OF ALL TRIALS PRODUCED IN 5 SECONDS	RATINGS FOR II. ASSOCIATED MOVEMENTS	RATINGS FOR III. ACCURACY	RATINGS FOR IV. SOUND STRUCTURE	OVERALL RATING FOR I. CONTINUITY
Tongue Diadochokinesis (-continued)					
[tə]	19.				
	20.				
	21.				
	22.				
	23.				
	24.				
DDR: ______	25.				
[kə]	1.				
	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				
	11.				
	12.				
	13.				
	14.				
	15.				
	16.				
	17.				
	18.				
	19.				
	20.				
	21.				
	22.				
	23.				
	24.				
DDR:_____	25.				
	26.				

APPENDIX C (-CONTINUED):

TARGET	TRANSCRIPTIONS OF ALL TRIALS PRODUCED IN 5 SECONDS	RATINGS FOR II. ASSOCIATED MOVEMENTS	RATINGS FOR III. ACCURACY	RATINGS FOR IV. SOUND STRUCTURE	OVERALL RATING FOR I. CONTINUITY
Glottal Diadochokinesis					
	1.				
[pəbə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				
	11.				
DDR: ____	12.				
	13.				
Tongue Diadochokinesis					
	1.				
[tə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				
	11.				
	12.				
	13.				
	14.				
	15.				
	16.				
	17.				
	18.				

APPENDIX C (-CONTINUED):

TARGET	TRANSCRIPTIONS OF ALL TRIALS PRODUCED IN 5 SECONDS	RATINGS FOR II. ASSOCIATED MOVEMENTS	RATINGS FOR III. ACCURACY	RATINGS FOR IV. SOUND STRUCTURE	OVERALL RATING FOR I. CONTINUITY
Combined diadochokinesis in Two-place CV-CV syllable strings					
	1.				
[pəkə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				
	11.				
	12.				
	13.				
DDR:____	14.				
	15.				
	1.				
[təkə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				

APPENDIX C (-CONTINUED):

TARGET	TRANSCRIPTIONS OF ALL TRIALS PRODUCED IN 5 SECONDS	RATINGS FOR II. ASSOCIATED MOVEMENTS	RATINGS FOR III. ACCURACY	RATINGS FOR IV. SOUND STRUCTURE	OVERALL RATING FOR I. CONTINUITY
Lip Diadochokinesis					
	1.				
[pə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				
	11.				
	12.				
	13.				
	14.				
	15.				
	16.				
	17.				
	18.				
	19.				
	20.				
	21.				
	22.				
	23.				
	24.				
DDR:_____	25.				

APPENDIX C (-CONTINUED):

TARGET	TRANSCRIPTIONS OF ALL TRIALS PRODUCED IN 5 SECONDS	RATINGS FOR II. ASSOCIATED MOVEMENTS	RATINGS FOR III. ACCURACY	RATINGS FOR IV. SOUND STRUCTURE	OVERALL RATING FOR I. CONTINUITY
Combined diadochokinesis in Three-place CV-CV-CV Syllable strings					
	1.				
[pətəkə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
DDR: _____	10.				
	1.				
[kətəpə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
DDR: _____	10.				
	1.				
[təpəkə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
DDR: _____	10.				

APPENDIX C (-CONTINUED):

TARGET	TRANSCRIPTIONS OF ALL TRIALS PRODUCED IN 5 SECONDS	RATINGS FOR II. ASSOCIATED MOVEMENTS	RATINGS FOR III. ACCURACY	RATINGS FOR IV. SOUND STRUCTURE	OVERALL RATING FOR I. CONTINUITY
Combined diadochokinesis in Two-place CV-CV syllable strings (-continued)					
	11.				
[təkə] (continued)	12.				
	13.				
	14.				
DDR:____	15.				
	1.				
[kəpə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
	9.				
	10.				
	11.				
	12.				
	13.				
DDR:_____	14.				
	15.				
	1.				
[kətə]	2.				
	3.				
	4.				
	5.				
	6.				
	7.				
	8.				
DDR:_____	9.				
	10.				

APPENDIX D (-CONTINUED):

AFRIKAANS -CCC/ -CC-CLUSTERS IN FINAL WORD POSITION

TARGET UNIT	TRANSCRIBED PRODUCTION	DESCRIPTION
[lm]		
[lf]		
[lx]		
[lp]		
[lt]		
[mp]		
[nt]		
[ŋk]		
[ls]		
[ts]		
[ks]		
[ns]		
[ps]		
[xs]		
[rs]		
[rk]		
[rx]		
[rf]		
[rp]		
[rm]		
[rt]		
[rts]		
[ŋks]		

RESULTS:

TOTAL FOR INITIAL CLUSTERS: $\frac{\_\_\_}{29}$ = ____%

TOTAL FOR FINAL CLUSTERS: $\frac{\_\_\_}{24}$ = ____%

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APPENDIX D: RECORDING/ANALYSIS SHEET FOR SUB-AIM FOUR

NAME OF CHILD: ______________________________ **DATE TESTED:** __________
DATE OF BIRTH: __________ **CHRONOLOGICAL AGE:** ________

AFRIKAANS CC-/CCC-CLUSTERS IN INITIAL WORD POSITION

TARGET UNIT	TRANSCRIBED PRODUCTION	DESCRIPTION
[pl]		
[kl]		
[xl]		
[fl]		
[bl]		
[fn]		
[kn]		
[kw]		
[tw]		
[dw]		
[sl]		
[sw]		
[sn]		
[st]		
[sk]		
[sm]		
[sp]		
[spl]		
[kr]		
[xr]		
[vr]		
[fr]		
[pr]		
[tr]		
[br]		
[dr]		
[skr]		
[spr]		
[str]		

APPENDIX F: RECORDING/ANALYSIS SHEET FOR SUB-AIM EIGHT

ACOUSTICAL MEASUREMENT OF FIRST-SYLLABLE DURATION IN WORDS OF INCREASING LENGTH

NAME OF CHILD: ______________________________ **DATE TESTED:** __________
DATE OF BIRTH: _________ **CHRONOLOGICAL AGE:** _______

Word Group (Wg) Number	Transcribed Word	Duration of first CV/CCV-syllable in seconds
1	[tæl]	
	[tæləŋ]	
	[tæləfo:n]	
2	[bak]	
	[baki]	
	[bakərəi]	
3	[duk]	
	[dukə]	
	[duksakə]	
4	[pan]	
	[panə]	
	[panəkuk]	
5	[blɔm]	
	[blɔmə]	
	[blɔmbakə]	
6	[kɔp]	
	[kɔpis]	
	[kɔpici]	
7	[knɔp]	
	[knɔpə]	
	[knɔpici]	
8	[ləp]	
	[ləpə]	
	[ləpstəfi]	
9	[man]	
	[manə]	
	[manici]	
10	[fən]	
	[fənə]	
	[fənəx]	

NOTES:

APPENDIX E: RECORDING/ANALYSIS SHEET FOR SUB-AIMS SIX AND SEVEN

ACOUSTIC MEASUREMENT OF FIRST-VOWEL DURATION AND VOICE ONSET TIME

NAME OF CHILD: ______________________ **DATE TESTED:** ________ **DATE OF BIRTH:** ________ **CHRONOLOGICAL AGE:** _____

MATERIAL		FIRST-VOWEL DURATION IN SECONDS					VOT-VALUE OF INITIAL STOP IN SECONDS				
Trans-cription	Afrikaans	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
[paki]	pakkie										
[baki]	bakkie										
[tasə]	tasse										
[dasə]	dasse										
[tɔpi]	toppie										
[dɔpi]	doppie										
[tək]	tik										
[dək]	dik										
[katə]	katte										
[fənəx]	vinnig										
[knəbəl]	knibbel										
[klɔki]	klokkie										
[blɔki]	blokkie										

NOTES:

APPENDIX G (-CONTINUED):

SETTING FOR SUB-AIMS 6, 7 AND 8:

(#58, 1sec)

KAY ELEMETRICS CORP. MODEL 5500
SIGNAL ANALYSIS WORKSTATION

Date: 3F 19FF Rec. Off Time:12:00:00 AM
Analysis by:

INPUT SETTINGS	Channel 1	Channel 2
Source	LEFT CONNECTORS	ALL MEMORY FOR CH1
Frequency Range	DC - 8 KHz.	DC - 8 KHz.
Input Shaping	HI-SHAPE	HI-SHAPE
Buffer Size	14.0 SECONDS	14.0 SECONDS

ANALYSIS SETTINGS	Lower Screen	Upper Screen
Signal Analyzed	CHANNEL 1	CHANNEL 1
Analysis Format	SPECTROGRAPHIC	WAVEFORM
Transform Size	100 pts. (300 Hz)	100 pts. (300 Hz)
Time Axis	50ms (1sec)	50ms (1sec)
Frequency Axis	FULL SCALE	FULL SCALE
Analysis Window	HAMMING	HAMMING
Averaging Set Up	NO AVERAGING	NO AVERAGING

DISPLAY SETTINGS	Lower Screen	Upper Screen
Freq. Divisions	1000. Hz.	0.000 Hz.
Dynamic Range	42 dB	42 dB
Analysis Atten.	25 dB	20 dB

Set Up Options Set to: # 58

CURSOR READINGS:
FC1: , FC2: , ^F:
FC1: dB, FC2: dB, ^F: dB
^R1: ^R2:
^T:
PITCH TC1: Hz. TC2: Hz.
AMPLITUDE TC1: dB TC2: dB

SUBJECT MATTER

APPENDIX G: SPECTROGRAPH SETTINGS

SETTING FOR SUB-AIM 3:

(#57, 8sec)

```
KAY ELEMETRICS CORP. MODEL 5500
SIGNAL ANALYSIS WORKSTATION

Date: N 3F 19FF                 Rec. Off Time:12:00:00 AM
Analysis by:

INPUT SETTINGS       Channel 1             Channel 2
Source               LEFT CONNECTORS       ALL MEMORY FOR CH1
Frequency Range      DC -  8 KHz.          DC -  8 KHz.
Input Shaping        FLAT                  HI-SHAPE
Buffer Size          14.0 SECONDS          14.0 SECONDS

ANALYSIS SETTINGS    Lower Screen          Upper Screen
Signal Analyzed      CHANNEL 1             CHANNEL 1
Analysis Format      SPECTROGRAPHIC        WAVEFORM
Transform Size       50 pts. ( 600 Hz)     100 pts. ( 300 Hz)
Time Axis            400ms    (8sec)       400ms    (8sec)
Frequency Axis       FULL SCALE            FULL SCALE
Analysis Window      HAMMING               HAMMING
Averaging Set Up     NO AVERAGING          NO AVERAGING

DISPLAY SETTINGS     Lower Screen          Upper Screen
Freq. Divisions       1000. Hz.             0.000 Hz.
Dynamic Range        42 dB                 72 dB
Analysis Atten.      20 dB                 20 dB
Set Up Options Set   to:  # 57

CURSOR READINGS:
FC1:               , FC2:               , ^F:
FC1:       dB,  FC2:       dB,  ^F:       dB
^R1:                     ^R2:
^T:
PITCH       TC1:     Hz.   TC2:       Hz.
AMPLITUDE   TC1:     dB    TC2:       dB

SUBJECT MATTER
```

APPENDIX H: EXAMPLES OF ANALYSIS GUIDELINES COMPILED FOR SUB-AIM ONE

* ***Target:*** *Lick ice cream (1.3. on Recording Form):*
Execution: Lift head up while licking. Rating on I: c. (-associated movement of the body)
Execution: Executed occasional in-out tongue-like movements as well as licking movements (in spite of the fact that the examiner demonstrated only licking movements outside the mouth) Rating on I:a; II:d (since licking was distorted by some in-out tongue movements).
Execution: Performed occasional circular licking movements in addition to upwards licking movements. Rating on I:a; II:d.

* ***Target:*** *Pout lips and lateralize tongue outside mouth (2.2. on Recording Form)*
Execution: Moved head (Rating on I:c. –due to associated movement of the body). Lateralized tongue *inside* mouth instead of on the *outside* (Rate on II:f -as it is incorrect placement); lateralized the tongue but touched the lip corners only occasionally (Rating on II:d -as it is correct placement but inaccurate execution). Simultaneously sucked cheeks in and pout lips instead of pouting only (Rating on II:d -since the pouting was only partly correct and distorted by sucking movement of cheeks, -can also be rated as an associated movement of cheeks, thus I:c. In a case like this where two of the same ratings occur, (the II:d -and I:c ratings), the ratings d. and c. are only *once respectively* on the recording/analysis sheet, in order to simplify the rating procedure. Rate III:a, since target movements were attempted in the correct sequence.
Execution: Moved mandible (Rate I:b). Pout lips correctly. Left-right tongue movements were sometimes accurate but sometimes distorted by inaccurate touching of lip corners and occasional touching of bottom-lip (Rate:II:d). Correct sequencing was obtained but only when key-words were provided before execution of a target movement (Rate III:c.).

* ***Target:*** *Puff cheeks and lateralize tongue (2.3. on Recording Form):*
Execution: Puffed cheeks but performed in-out tongue movements instead of left-right ones. Rating on I:a; II:a; III:f (-since some of the movements in the target sequence were incorrect); IV:f . Since one part of the sequence was performed incorrectly, no rating is possible in category III. It thus follows that if an f. or g. is assigned in Category II., no rating is possible in Category III. This rule was maintained throughout the rating procedure for non-speech oral movements.

* ***Target:*** *Pout lips, puff cheeks,stick out tongue (3.1. on Recording Form):*
Execution: Puffed cheeks correctly, pout lips correctly. Lateralized tongue sometimes although in-out movement was maintained. Rating on I:a; II:d. Could execute in correct sequence but was dependant on key words (Rating on III:c.).

* ***Target:*** *Blow a kiss, touch nose with tongue, blow out candle (3.2 on Recording Form):*
Child's execution: Kiss correctly, blew candle correctly, sequencing was correct, but tongue rested on lowerlip and chin was lifted up in order to try and touch nose. Key words were needed for correct sequencing. Rating on I:c; II:a; III:c.

APPENDIX I: EXAMPLES OF ANALYSIS GUIDELINES COMPILED FOR SUB-AIM THREE

***TARGET: [dənə]**
Production: [dədən] -first trial utterance
Rating: I:c (slow initiation due to first incorrect production); II:a; III:a (all sounds were accurately produced); IV: k (since it's not obvious how the sound structure was changed; multiple changes may have been possible).
Production: [dən-dən]
Rating I: a; II:a; III:a; IV: g (since [ə] was deleted); & IV:h (since part of the target utterance i.e. [dən] was repeated).

*** TARGET: [pəbə]**
Production: [bəbə]
Rating: I:a; II:a; III:d (voicing error); IV:c (as this can also be regarded as a substitution)
RULE: If voicing error (d) is rated in Category III and the target sound is substituted with a phonetically different sound, Category IV:c can also be rated (substitution) in order to cover all possibilities.
Production: [pəpə]
Rating: I:a; II:a; III:d (voicing error); IV:c (as this can also be regarded as a substitution)
RULE: If voicing error (d) is rated in Category III and the target sound is substituted with a phonetically different sound, Category IV:c or IV:d can also be rated in order to cover all possibilities.
Production: [bəpə]
Rating: I:a; II:a; III:d (two voicing errors); IV:c (two substitutions) as well as IV. j (transpositioning of syllables can also be applicable).
Production: [pə--pəpə] (first trial of the series, an initial restart)
Rating: I:c (continuity affected due to the subjects's interruption of own production, tried to self-correct); II:a; III:d (voicing error as target [b] was substituted with [p]); IV:c ([b] substituted with [p]) as well as IV:h., (since the first part of the target word i.e. [pə], was repeated on the restart).
Production: [bə--pəbə] (self correction on second trial of series)
Rating: I:d (mild arythmic as occurred only once in sequence); II:a; III:a (all sounds correct); IV:b (successful self-correction, -as deducted from contextual information e.g.intonation and break in production).

*** TARGET: [tə]**
Production: [də]
Rating: I:a; II:a; III:d (-since [t] was substituted for voiced counterpart [d] which is a voicing error); IV: d (as the [t] was clearly substituted for a phonetically different sound [d] and can thus also be rated as a substitution with a non-target sound)

*** TARGET: [kə]**
Production: [k + distorted production of ə]
Rating: I:a; II:a; III:f (as it is only a mild inaccurate production of one vowel); IV:a (sound structure accurate in spite of mild distortion; none of sound structure error ratings applicable)

*** TARGET: [pəkə]**
Production: [pəkə--kə]
Rating: I:a; II:a; III:a; IV:e (addition of syllable)

*** TARGET: [kəpə]**
Production: [kəpkə]
Rating: I:a; II:a; III:a; IV:f (sound insertion)

APPENDIX I (-CONTINUED):

*** TARGET: [təkə]**
Production: [tətə]
Rating: I:a; II:a; III:a; IV:c
Production: [təkxə]
Rating: I:a; II:a; III:a; IV:f (sound insertion)

*** TARGET: [kətə]**
Production: [təkə-tə] (first two syllables grouped together by intonation and stress)
Rating: I:a (good rhythm throughout productions); II:a; III:a (all sounds were produced accurately); IV:j (can regard first CVCV-part as transposition of syllables on basis of intonation/phrasing); can also rate IV:e (since a CV-syllable was also added).
Production: [təkə--tə]
Rating: I:d (mild, happened only once in 9 productions); II:a; III:a; IV:a

*** TARGET: [pətəkə]**
Production: [pəkətə]
Rating: I:a; II:a; III:a; IV:j (transpositioning)
Production: [pə-pətəkə] (self-correction on 6th trial)
Rating: I:d (mildly arythmic due to self-correction); II:a; III: a; IV:b (successful self-correction)
Production: [patəkə]
Rating: I:a; II:a; III:a (all sounds were produced accurately); IV:d (substitution of [ə] with [a])
Production: [pəktəkə] (first trial, slower than following trials)
Rating: I:c (due to slow inititaion); II:a; III:a; IV:f (insertion)
Production: [pəkətək]
Rating: I:d (since self-correction interfered with rhythm later in sequence); II:a; III:a; IV:j (transpositioning of [t] & [k]) as well as IV:e (addition of [k])
Production: [tə--pətəkəp] (self-correction -although unsuccessfull- on 5th utterance)
Rating: I:d; II:a; III:a; IV:e & e (two e-ratings due to addition of syllable [tə] as well as consonant [p])

*** TARGET: [kətəpə]**
Production: [təpə-təkətə-pə] (first trial in sequence)
Rating: I:c (slow initiation); II:a; III:a; IV:k (since multiple changes in phoneme structure occurred)
Production: [kəptə]
Rating: I:d (mild arythmic production occured in following trials); II:a; III:a; IV:j (transpositioning of [p] & [t]) as well as IV:g (deletion of [ə])
Production: [kətəkbə]
Rating: I:d (since rhythm was mildly intermittant throughout production of sequence); II:a; III:d (voicing error: [p] substituted with [b]; IV:d (substitution of [p] with [b]-a sound not in target utterance) as well as IV:f (insertion of [k]).
Production: [kəp-kətəpə]
Rating: I:d; II:a; III:a; IV:b (rated as successful self correction and not syllable addition based on suprasegmental information and since rest of utterance was correct with regards to sound structure).

*** TARGET: [təpəkə]**
Production: [təpətəktəp]
Rating: I:d (general rhytm was intermittent); II:a; III:a; IV:k (multiple changes in phoneme structure)
Production: [təkə]
Rating: I:a; II:a; III:a; IV:g (second syllable of target utterance was deleted)
Production : [pəkəkə]
Rating: I:d (general intermittent execution); II:a; III:a; IV: c & IV:c. (rated twice, since two possible substitutions occurred); can also rate IV.k. (multiple changes in phoneme structure), in order to cover all possibilities

APPENDIX I (-CONTINUED):

Production: [pəkətə]
Rating: I:d (general intermittent execution); II:a; III:a; IV: j (since syllable order was transpositioned)