Perceptual parameters of speech production in childhood apraxia of speech: The effects of speech motor learning treatment

by

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A dissertation submitted in fulfilment of the requirements for the degree

M. Communication Pathology

in the Department of Speech-Language Pathology and Audiology at the

UNIVERSITY OF PRETORIA
FACULTY OF HUMANITIES

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April 2015

Acknowledgements

- Firstly, I would like to express my gratitude to my supervisor Prof. Anita van der Merwe, for her patient guidance and her commitment to excellence throughout the duration of this research project. Thank you for sharing your research and clinical expertise with me, for investing so much of your time and energy in this project and for supporting my growth as a young researcher in so many different ways.

- I would also like to thank my co-supervisor, Dr. Diane Kendall, whose extensive knowledge and practical guidance has contributed a great deal to this research project. I sincerely appreciate the valuable and enthusiastic advice and support you have provided.

- I would like to acknowledge and thank the Participant and his parents for their participation in this study. I admire your courage and perseverance, and am privileged to have been a small part of your lives.

- To the Participant's private speech-language therapist: thank you for your willingness to be a part of this study and for the support you provided throughout the treatment period. I sincerely appreciate your contribution.

- To my parents, my other family members and my friends: thank you for your love, encouragement and prayers, which have supported me throughout this project.

- Finally, to Jesus Christ: thank you for Your unconditional love and grace, and for helping me climb this mountain.

Summary

Background. The diagnosis and treatment of childhood apraxia of speech (CAS), a sensorimotor speech disorder in children, is both challenging and controversial. Uncertainty exists regarding the disorder's underlying nature and its salient features. This uncertainty impacts the formulation of treatment approaches. Numerous approaches for CAS treatment have been suggested, based on different authors' theoretical conceptualisation of the disorders' underlying nature and its characteristic features. Research on many of these approaches report improvements in items targeted in treatment, but generalisation to untreated items and maintenance of skills varies. Factors which influence the outcomes of treatment include the treatment methods, as well as the types of targets selected. Authors tend to attribute improvements achieved by participants to the methods employed in a particular treatment. Comparatively little theoretical consideration is given to the selection of targets and the influence this has on treatment, generalisation and maintenance effects. The current study investigated the speech motor learning (SML) approach (Van der Merwe, 1985; 2011), which is based on a comprehensive speech motor planning and programming model (Van der Merwe, 1997; 2009). This model aids one in understanding the nature of CAS and predicts many of its characteristic features. Furthermore, the model provides guidelines for treatment targets in particular, but also for treatment methods.

Aims. The primary aim was to determine whether the SML approach would effect a positive change in the speech production of a child with CAS, as measured by *whole word accuracy*. The sub-aims were to determine whether treatment effects would

generalise to untreated non- and real-word stimuli containing: 1) only *treated* age-appropriate consonants and five vowels (Set 1 sounds); 2) in addition, *untreated* age-appropriate consonants and the same five vowels (Set 2 sounds); 3) in addition, *untreated age-inappropriate* consonants and the same five vowels (Set 3 sounds).

Method. A single-case experimental design, with multiple baselines and multiple probes across behaviours was implemented. The Participant, a 33-month old boy, presented with a cluster of CAS symptoms. He received 18 sessions of treatment according to the SML approach (Van der Merwe, 1985; 2011) over 9 weeks. Three baseline, nine treatment, and two follow-up probes were performed across the study duration. Probe stimuli comprised untreated non- and real-words containing treated (Set 1) and untreated (Set 2: age-appropriate and Set 3: age-inappropriate) sounds. Whole word accuracy was determined through perceptual analysis. Accuracy scores were compared through effect size (ES) calculations. A post-hoc analysis on error types was performed to explore the effect of improvement on the nature of errors across time.

Results. The Participant demonstrated a significant improvement in the accuracy of treated sounds (Set 1), while less or no change was observed in untreated age-appropriate (Set 2) and untreated age-inappropriate (Set 3) consonants respectively. The post-hoc analysis revealed a predominance of phonetic-motoric errors throughout the study. Set 3 real words showed a small increase in phonological errors, with a coinciding decrease in the number of words that were distorted to such an extent that individual sounds could not be distinguished.

Conclusions. The SML approach was effective in improving the Participant's ability to plan and coarticulate sounds, resulting in significantly improved production of treated sounds in untreated nonword exemplars and untreated real words. Generalisation of treatment gains to untreated stimuli provides support for the target selection of the SML approach, in addition to the SML methods as implemented in this study. The predominance of phonetic-motoric errors supports the notion that CAS is a disorder of motor planning and/or programming.

KEYWORDS: Childhood apraxia of speech (CAS), developmental dyspraxia, treatment, intervention, speech motor learning approach, speech production, speech signs, nature of errors, phonetic-motoric, perceptual analysis.

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Title of dissertation: **Perceptual parameters of speech production in childhood apraxia of speech: The effects of speech motor learning treatment**

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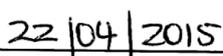
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Definitions of terminology

The following list of terminology, and the definitions that follow, are provided as a quick reference to clarify the meaning of terms as applied in this study. In addition, this section provides background information on some topics, which, though important, would otherwise interrupt the flow of the content and arguments in the text.

List of terminology

Childhood apraxia of speech

Acquisition and learning of motor skills

Generalisation

Maintenance

Principles of motor learning

Integral stimulation

Five-phase outcomes research model

Levels of evidence

Single case experimental design

Phonetic-motoric errors

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Definitions

Childhood apraxia of speech (CAS)

Childhood apraxia of speech (CAS) is defined by the American Speech-Language-Hearing Association (ASHA, 2007, p. 3-4) as

> "… a neurological childhood (pediatric) speech sound disorder in which the precision and consistency of movements underlying speech are impaired in the absence of neuromuscular deficits (e.g. abnormal reflexes, abnormal tone). CAS may occur as a result of known neurological impairment, in association with complex neurobehavioural disorders of known or unknown origin, or as an idiopathic neurogenic speech sound disorder. The core impairment in planning and/or programming spatiotemporal parameters of movement sequences results in errors in speech sound production and prosody."

Other terms which have been used to describe this disorder in the past include developmental apraxia of speech (DAS), developmental verbal dyspraxia (DVD), and articulatory dyspraxia. The term "childhood apraxia of speech" was recommended as the preferred term by the ASHA (2007) technical report committee. "CAS" is used throughout this dissertation and is intended to include references to other, earlier terms.

Acquisition and learning of motor skills

In the motor learning literature, a distinction is made between *acquisition* (performance) and *learning* of motor skills (Robin, Maas, Sandberg, & Schmidt, 2007, p. 78; Schmidt & Lee, 1999, p. 265; 2005). The term "acquisition" refers to the initial acquisition of a motor skill and an individual's performance within a particular

treatment session. "Learning" refers to a permanent change in motor skill, reflected in the transfer of a skill to conditions outside treatment (Maas et al., 2008; Magill, 2007, p. 438, 440; Schmidt & Lee, 1999, p. 415).

Generalisation

Generalisation (or transfer) is observed when a newly learned motor skill is applied outside the treatment condition (Maas et al., 2008; Magill, 2007, p. 291; Schmidt & Lee, 1999, p. 389). Two types of generalisation have been specified. Response generalisation refers to the transfer of treated behaviours (movements) to untreated stimuli that are similar or related to treatment stimuli (Ballard, 2001; Olswang & Bain, 1994). Stimulus generalisation refers to the transfer of treated behaviours to untreated and unrelated contexts (Ballard, 2001; Olswang & Bain, 1994).

Maintenance

Maintenance (or retention) refers to the ability to retain a learned motor skill after treatment on this skill has been terminated (Maas et al., 2008; Magill, 2007, p. 253; Schmidt & Lee, 1999, p. 387).

Principles of motor learning

In the motor learning literature, reference is made to certain principles of motor learning (PML) which "guide how the motor system learns" (Robin et al., 2007, p. 77). Given that speech production is a motor skill, PML are increasingly applied in the treatment of motor speech disorders (Maas et al., 2008) to promote learning and generalisation (Schmidt & Lee, 1999, p. 286). The PML discussed below include pre-practice, the conditions of practice and the nature of feedback:

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- **Pre-practice**

Pre-practice is aimed at preparing the client for learning before treatment commences (Robin et al., 2007, p. 78; Schmidt & Lee, 1999, p. 286). Important precursors to learning which must be fostered during pre-practice are: the client's trust, motivation and attention, as well as an understanding of the session goals and targets through clear instructions and modelling (Robin et al., 2007; Schmidt & Lee, 1999; 2005; Strand & Skinder, 1999).

- **Conditions of practice**

Conditions of practice include practice amount, practice schedule, distribution of practice, variability of practice, mental practice, as well as part-whole methods:

- Practice *amount* refers the number of trials or repetitions of a target skill within a practice session (Schmidt & Lee, 1999, p. 286) and may be *small* or *large*. A small practice amount would be few practice trials or a low frequency of production (e.g. 20 trials per sessions), while a large practice amount would be numerous trials or a high frequency of production (e.g. 100 trials per session) (Robin et al., 2007, p. 83; Schmidt & Lee, 1999, p. 286).

- The practice *schedule* may be blocked or random (Robin et al., 2007, p. 81; Schmidt & Lee, 1999, p. 303). In *blocked* practice, one target is practiced for a specific time (a "block") before moving to the next target, which is then practiced for a specific time. *Random* practice refers to the simultaneous practice of several targets in an unpredictable (random) order (Magill, 2007, p. 373; Schmidt & Lee, 1999, p. 303).

- The *distribution* of practice can refer to the number of practice sessions in a given time period, the length of a session, as well as the time between

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consecutive sessions (Magill, 2007, p. 402-403). *Massed* practice refers to fewer, but longer sessions with more time between sessions, for example, a 60 minute session once a week for four weeks. On the other hand, *distributed* practice refers to shorter, more frequent sessions, for example, a 20 minute session three times a week for four weeks (Magill, 2007, p. 402-403).

- Practice *variability* is defined as "the variety of movement and context characteristics a person experiences while practicing a skill" (Magill, 2007, p. 369). V*ariable* practice involves practice of a target in a number of different contexts, while *constant* practice involves practicing a target in an unvaried context (Magill, 2007, p. 369; Robin et al., 2007, p. 81; Schmidt & Lee, 1999, p. 298).

- *Mental practice* entails the covert or internal rehearsal of a skill by thinking about the cognitive elements of the skill or imagining the performance of the skill (Magill, 2007, p. 439; Schmidt & Lee, 1999, p. 416).

- *Part-whole methods* is defined by Schmidt and Lee (2005, p. 466) as a "learning technique in which the task is broken down into its parts for separate practice." *Part* practice "would seem to be an effective procedure when the task is very complex and cannot be grasped as a whole" (Schmidt & Lee, 1999, p. 313).

- **Types of feedback**

There are two main types of feedback: intrinsic and augmented feedback (Magill, 2007, p. 332; Robin et al., 2007, p. 84; Schmidt & Lee, 1999, p. 324).

- *Intrinsic* feedback refers to information about the performance of a skill which an individual receives through his/her own sensory system. This information

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may be auditory, visual, tactile or proprioceptive (Magill, 2007, p. 332; Schmidt & Lee, 1999, p. 324).

- *Augmented* feedback is information about the performance which is provided from an external source, in addition to intrinsic feedback (Magill, 2007, p. 332; Schmidt & Lee, 1999, p. 325). Augmented feedback can be divided further into knowledge of performance and knowledge of results feedback.

- *Knowledge of performance (KP)* is a type of augmented feedback which involves information about the characteristics of the movements performed (Magill, 2007, p. 334; Schmidt & Lee, 1999, p. 326). For example, "Yes, that was great, you got your lips together" (Robin et al., 2007, p. 84).

- *Knowledge of results (KR)* feedback refers to information about the accuracy of the outcome of movement (Magill, 2007, p. 333; Schmidt & Lee, 1999, p. 325). For example, "Yes, that was correct" (Robin et al., 2007, p. 84).

- **Frequency and timing of feedback**

The frequency and timing of feedback may influence the effectiveness of the augmented feedback provided.

- The *frequency* of feedback refers to the how often augmented feedback is provided (Maas et al., 2008; Robin et al., 2007, p. 85). Feedback given on all trials is considered a *high* frequency, while feedback given on only some trials (e.g. 50%) is a *low* frequency (Magill, 2007, p. 357; Robin et al., 2007, p. 84; Schmidt & Lee, 1999, p. 339).

- With regard to *timing*, feedback may be given while a task is being performed (*concurrent* feedback), *immediately* after a task is performed or after a *delay* of a few seconds (Magill, 2007, p. 364; Robin et al., 2007, p. 85).

- Related to feedback frequency and timing, is the concept of *summary* feedback, in which summative KR feedback is given after a specific number of trials (Maas et al., 2008; Magill, 2007, p. 362; Schmidt & Lee, 1999, p. 420). For example, "The first two were accurate; the last two were incorrect" (Robin et al., 2007, p. 85).

Integral stimulation

Informally referred to as "watch me, listen and do what I do," integral stimulation is a procedure which involves a client imitating a clinician after looking at, and listening to, the clinician's model of an utterance. Integral stimulation therefore promotes the shaping of speech movements through imitation (Edeal & Gildersleeve-Neumann, 2011; Maas, Gildersleeve-Neumann, Jakielski, & Stoeckel, 2014; Strand & Skinder, 1999). Initially applied in the treatment of articulation disorders, as well as dysarthria and acquired apraxia of speech (Rosenbek, Lemme, Ahern, Harris, & Wertz, 1973), integral stimulation is recommended as a treatment strategy in CAS treatment (Edeal & Gildersleeve-Neumann, 2011; Maas et al., 2014; Strand & Skinder, 1999).

Five-phase outcomes research model

Research on a new treatment approach ought to follow a systematic progression over time to ensure its acceptance as evidence-based practice (Wertz, 2002). The five-phase outcomes research model has been adapted by Robey and Schultz (as cited in Robey, 2004; Wertz, 2002) to direct research on treatment approaches in the field of Speech-Language Pathology. The five research phases in this model are presented in Table I, together with the study designs which are appropriate for each phase (Robey, 2004; Wertz, 2002).

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Table I. Robey & Schultz's five-phase outcomes research model (summarised from Robey, 2004 and Wertz, 2002, p. xii-xiii).

Research phase	Objectives of the research phase	Appropriate study designs
I (Discovery)	The hypothesis about the treatment is developed and the safety of the treatment is confirmed. The researcher establishes that there is some change in participants who receive the treatment	Single-participant and small, single-group experimental designs
II (Refinement)	The hypothesis is refined and the researcher seeks to explain why the treatment may work. The ideal conditions (participants, clinicians, treatment protocol, dosage, outcomes measures) are determined	Single-participant and small, single-group experimental designs
III (Efficacy)	The probability of benefit is tested under *ideal* conditions, that is, participants, treating clinicians, treatment, intensity, duration and outcomes measures which are all *ideal*	Randomised controlled trials with large groups of participants
IV (Effectiveness)	The probability of benefit is tested under average*, or *typical,* conditions, that is, participants, treating clinicians, treatment, intensity, duration and outcomes measures which are all *typical*	Single-participant experiments with multiple replications and large, single-group experiments
V (Efficiency)	Effectiveness continues to be examined. Aspects such as efficiency, cost-effectiveness, cost-benefit, cost-utility, family satisfaction and effect of treatment on participant's quality of life are investigated	Single-participant experiments with multiple replications and large, single-group experiments

Levels of evidence

The quality of evidence generated by a particular treatment study should be judged before its findings are implemented. Different evidence rating systems are used depending on the type of research that is evaluated (ASHA, 2004). The evidence hierarchy of the Scottish Intercollegiate Guideline Network (SIGN) (as cited in ASHA,

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2004) is presented in Table II, as an example of a rating system which has been applied in research on childhood speech-language disorders (Johnson, 2006).

Table II. Levels of evidence for studies of treatment efficacy (from Scottish Intercollegiate Guideline Network, www.sign.ac.uk, as adapted and cited by ASHA [2004]).

Level	Description
Ia *	Well-designed meta-analysis of more than one randomized controlled trial
Ib	Well-designed randomized controlled study
IIa	Well-designed controlled study without randomization
IIb	Well-designed quasi-experimental study
III	Well-designed non-experimental study, i.e., correlational and case study
IV	Expert committee report, consensus conference, clinical opinion of respected experts, professional consensus

* Highest level of evidence

Another perspective suggests that studies can be judged according to the *level of certainty* that the findings reported by a specific treatment study are true (Smith, 1981). Three levels of certainty have been proposed by Smith (1981) and are displayed in Table III:

Table III. Smith's (1981, p. 274) levels of certainty evidence rating system.

Level of certainty	Description
I (Suggestive evidence)	Studies demonstrating that a particular outcome or finding is "possibly true"
II (Preponderant evidence)	Studies which demonstrate that a particular outcome or finding is "probably true"
III (Conclusive evidence) *	Studies demonstrating that an outcome or finding is "undoubtedly true"

* Highest level of evidence

The American Academy of Neurology (AAN, 2011) proposes classifying evidence according to four classes, based on an estimate of a study's risk of bias (inaccurately measuring a treatment effect). A summary of this classification is depicted in Table IV:

Table IV. AAN (2011, p. 8-9, 38) classification of the evidence of treatment studies.

Class	Description
I *	Randomised, controlled trials (RCTs) using a representative population Requirements: clearly defined criteria for inclusion / exclusion, sufficiently similar participant characteristics at baseline, blind allocation of participants to treatment or control group, clearly defined outcomes and masked or objective outcomes assessment Risk of bias is *low*
II	Cohort, case-control studies meeting Class I requirements or RCTs not meeting all Class I requirements Risk of bias is *moderate*
III	Controlled studies (including within-participant designs), in which confounding differences between groups are described and outcomes assessment is masked, objective or independent from the treatment team Risk of bias is *moderately high*
IV	Uncontrolled studies, using participants who do not clearly meet inclusion criteria, treatment approaches which are not clearly defined or unsuitable outcomes measures Risk of bias is *very high*

* Highest level of evidence

Single case experimental design (SCED)

Single case experimental design (SCED) refers to a research design in which the components of a treatment are scientifically investigated to identify the variable that is responsible for success, with specific application to one or a few individual participants who serve as their own controls (with-in participant experimental design). The researcher manipulates a single independent variable and observes the effect on the dependent variable (change in behaviour), by means of repeated

probes of well-defined outcomes measures across time (Barlow, Nock, & Hersen, 2009, p. 4-10, 29; McReynolds & Kearns, 1983, p. 1-9). There are six types of SCED: pre-experimental (AB) design, withdrawal (ABA or ABAB) design, multiple-baseline/multiple-probe design, changing criterion design, multiple-treatment design, and alternating treatment design (Barlow et al., 2009; Byiers, Reichle, & Symons, 2012; McReynolds & Kearns, 1983). SCEDs are relevant to research in the field of Speech-Language Pathology, as they allow a focus on the individual and can be used to initially demonstrate the effectiveness of a particular treatment (Beeson & Robey, 2006; Byiers et al., 2012; McReynolds & Kearns, 1983, p. 6-9). Level IIb evidence can be derived from well-designed, rigorous SCEDs (Byiers et al., 2012; Gierut & Morrisette, 2011).

Phonetic-motoric errors

The term "phonetic" refers to the production of speech sounds and the acoustic, physiological (including movement or motoric) and perceptual properties of different sounds (Borden, Harris, & Raphael, 1994, p. 302; Ohde & Sharf, 1992, p. 1-9). Phonetics is differentiated from phonology (phonemics), which relates to the use of sounds to distinguish meaning in a specific language and the rules for structuring sounds in words (Borden et al., 1994, p. 302; Ohde & Sharf, 1992, p. 4). The term "phonetic-motoric" is used by McNeil and colleagues (McNeil, Robin, & Schmidt, 1997; 2009, p. 264) to explain the nature of apraxia of speech and to indicate that a motor disorder (as opposed to a linguistic disorder) impacts phonetic aspects of speech production. McNeil used the term phonetic-motoric to rule out confusion with the phonological level of speech production and to aid in differentiating between apraxia of speech and phonemic paraphasia (McNeil et al., 1997; 2009). The term

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phonetic-motoric particularly focusses on the motoric, or movement, aspects of speech.

Distortion

Distortions refer to inaccurate productions or non-allophonic variations of a specific sound (Ohde & Sharf, 1992, p. 322). In this study, distortions were classified as phonetic-motoric errors as they are believed to arise due to disruptions in the temporal or spatial specifications of movements for sound segments, or distorted coarticulation between sound segments (McNeil et al., 1997; 2009, p. 264; Van der Merwe, 1997; 2009; 2011; Van der Merwe, Uys, Loots, Grimbeek, & Jansen, 1989).

Voice onset time

Voice onset time (VOT) is defined as the interval between the release of a plosive consonant and the onset of voicing (Borden et al., 1994, p. 307). Errors in VOT may result from an inability to correctly time and coordinate the movements of the oral articulators and vocal fold vibration (McNeil et al., 1997; 2009), reflecting a difficulty in the planning of inter-articulatory synchronisation (Van der Merwe, 1997; 2009). VOT errors, which include voicing of voiceless sounds or devoicing of voiced sounds, were noted as phonetic-motoric errors in this investigation.

Phonological errors

Phonological processing refers to the use of rules to select and combine phonemes to form words that are meaningful in the language (Ohde & Sharf, 1992, p. 4). Other terms used to refer to this linguistic process are phonological encoding (McNeil et al., 1997; 2009) or phonological planning (Van der Merwe, 1997; 2009). Speech level

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errors which arise from a deficit at the phonological level are termed phonological errors. In this study, additions, omissions, and trans-positioning of well-produced phonemes were considered *phonological* errors and were interpreted to reflect either incorrect selection of phonemes or incorrect sequential combination of phonemes (McNeil et al., 1997; 2009, p. 251-257; Van der Merwe, 1997; 2009). It is acknowledged that in speech development of children, the differentiation between motor and linguistic abilities is not always clear.

Ambiguous errors

Ambiguous errors are those errors which cannot adequately be attributed to either a motor or phonological level. Either a phonetic-motoric or a phonological breakdown may be a possible cause for the perceived error. An error at the phonological level may be an inaccurate selection or combination of phonemes (McNeil et al., 1997; 2009, p. 251-257; Van der Merwe, 1997; 2009), while an error at the motor level may be "intra- and interarticulatory temporal and spatial segmental distortions" (McNeil et al., 2009, p. 264), as a result of inaccurate motor planning (Van der Merwe, 1997; 2009). In this study, substitutions and distorted substitutions of consonants, as well as all vowel errors, were classified as ambiguous errors

Substitutions

A substitution is widely accepted as a linguistic term referring to the replacement of one phoneme for another, well-articulated phoneme (Ohde & Sharf, 1992, p. 207) and implies a phonological (linguistic) error.

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Distorted substitutions

The term "distorted substitution" is used by McNeil **et** al. (1997; 2009, p. 262-264) to refer to a characteristic of apraxia of speech in which a speech error is perceived as a substitution, but arises due to distortions of the intended sound. They attribute this error to the phonetic-motoric level (McNeil et al., 1997; 2009, p. 256).

Vowel errors

Vowel errors refer to inaccurate productions of a vowel (distortion) or substitutions of one vowel for another.

List of abbreviations

AAC: Augmentative and alternative communication

AOS: Acquired (adult) apraxia of speech

ASHA: American Speech-Language-Hearing Association

C: Consonant

CAS: Childhood apraxia of speech

CVCV: Consonant-vowel-consonant-vowel syllable structure

DTTC: Dynamic Temporal and Tactile Cueing approach

IPA: Integrated phonological awareness approach

KP: Knowledge of performance feedback

KR: Knowledge of results feedback

ReST: Rapid Syllable Transition Treatment

PML: Principle/s of motor learning

SML: Speech motor learning approach

SCED: Single case experimental design

V: Vowel

VOT: Voice onset time

WWA: Whole word accuracy

CHAPTER 1: LITERATURE REVIEW, PROBLEM STATEMENT AND RATIONALE

1. Introduction to Chapter 1

Since its initial description in the 1950's, childhood apraxia of speech (CAS) has been a subject of much controversy and debate in the field of Speech-Language Pathology. Uncertainty exists regarding the disorder's underlying nature and its salient features. Some authors have conceptualised the underlying deficit in CAS as a disorder in the motor planning and/or programming level of speech production (Hall, Jordan, & Robin, 2007; Maas & Farinella, 2012; Rosenbek & Wertz, 1972; Strand & Skinder, 1999)**,** while others have viewed it as a linguistic level problem (Aram, 1984; Crary, 1984; Marquardt, Sussman, Snow, & Jacks, 2002). In addition, the specific processes involved at each of these levels are poorly understood. A myriad of symptoms have been used to diagnose CAS, though the validity of these symptoms in differential diagnosis has not been demonstrated adequately. Consequently, both differential diagnosis and treatment of CAS remain challenging.

The uncertainty regarding the underlying nature of CAS impacts the formulation of treatment approaches. Treatment approaches for CAS have been categorised as motor, linguistic, a combination of motor and linguistic, or alternative and augmentative communication (AAC) approaches (ASHA, 2007; Hall et al., 2007; Murray, McCabe, & Ballard, 2014). Two of the three approaches identified as demonstrating preponderant evidence in a review by Murray et al. (2014) are motor-based, while the other one is linguistic. The distinction between motor and linguistic approaches has value in that it broadly alludes to the authors' theoretical opinion regarding the underlying nature of CAS as either a motoric or a linguistic disorder

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(Hall et al., 2007; Murray et al., 2014). However, most treatment approaches are not developed on the basis of specific, detailed theoretical models of the different processes involved in speech production.

One widely accepted theoretical model is the four level framework of speech sensorimotor control (Van der Merwe, 1997; 2009). This model provides a comprehensive description of motor planning of speech, which is the core deficit proposed to underlie apraxia of speech. The model adequately predicts the salient features of the disorder and also provides guidelines for its treatment (Ballard, Granier, & Robin, 2000). Based on this theoretical orientation, a treatment approach, the speech motor learning (SML) approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011), was developed for the treatment of acquired apraxia of speech (AOS) and CAS. As an approach that is grounded in the four level framework, the SML approach demonstrates potential in the treatment of apraxia of speech in both its developmental and acquired forms, because it aims to guide the client in acquiring, establishing and controlling motor planning of speech. Evidence in the form of case studies and single case experimental studies is available for this approach (Schulze-Hulbe, 2011; Van der Merwe & Tesner, 2000; Van der Merwe, 1985) and its theoretical basis, methods and results have been published internationally (Van der Merwe, 2007; 2011). Level III and IV evidence is available from Schulze-Hulbe (2011), Van der Merwe (1985), and Van der Merwe and Tesner (2000). The most recent systematic review on treatment in AOS (Ballard et al., 2015) rated Van der Merwe's (2007) investigation of the effect of treatment on self-corrections in AOS as Class IIIb evidence, and her 2011 publication on the SML approach as Class III evidence. Given the well-founded theoretical underpinning and

past success of the SML approach, the current study sought to further investigate the application of this approach to the treatment of CAS.

In this chapter, the scene for the current study is set through a description of the background of CAS and its definition, as well as the salient features of the disorder. A review of current research on CAS treatment, exploring various approaches and principles of treatment, is also provided. The nature of CAS is discussed within the context of the four level framework (Van der Merwe, 1997; 2009) and the rationale and methods of the SML approach (Van der Merwe, 1985; 2007; 2011) are presented. Lastly, the purpose of the current study is highlighted within the context of the aforementioned.

2. Childhood apraxia of speech: An overview of the disorder

2.1. A historical overview of apraxia of speech in children

Childhood apraxia of speech (CAS) is a severe, and often persistent, sensorimotor speech disorder in children. Consensus exists among researchers that the diagnosis and treatment of the disorder is both challenging and controversial. Several explanations for the controversy surrounding the diagnosis are often cited in the literature, including the diverse and often contradictory conceptualizations of the underlying nature of CAS, the uncertainty regarding its salient features, the different degrees of severity across children and the co-occurrence with other disorders (ASHA, 2007; Forrest, 2003; Hall et al., 2007). To gain insight into the debate surrounding this childhood speech disorder, researchers' and clinicians' understanding of the disorder, and how this understanding has developed since its initial description, will be explored.

One of the first reports of apraxia of speech in children was produced by Morley, Court, and Miller in 1954. In this report, Morley et al. (1954) described a group of 18 children diagnosed with variations of "developmental dysarthria," which were differentiated from dysarthria associated with cerebral palsy. Six of the 18 children presented with apparently normal voluntary movement of oral structures, which were "clumsy and awkward when the children attempted more complex and rapid movements of articulation" (Morley et al., 1954, p. 9). Other symptoms reported for this group included significantly reduced intelligibility, many consonant errors, difficulty imitating sounds without a visual model, and slow response to treatment. These symptoms were regarded as a form of "articulatory dyspraxia" (Morley et al., 1954, p. 9). The dysfunction was thought to originate at a neurological level *higher* than that which results in the paralysis or paresis of oral or limb musculature typically seen in dysarthria. Though not explicitly stated, a dysfunction in motor planning and/or programming was probably implied by Morley et al. (1954). Wilson (1964) applied a linguistically-orientated label, "childhood expressive aphasia," to children who presented with reduced expressive speech and language, limited to one or two-syllable utterances, and difficulties in imitating tongue, lip and jaw movements, as well as sounds or words, while their intelligence and language comprehension appeared normal.

Later, in a review of 50 children diagnosed with CAS, Rosenbek and Wertz (1972) argued that the characteristics used to describe the disorder "childhood expressive aphasia" were more appropriately explained by a deficit in motor programming than a central language disorder. They suggested using the term *developmental apraxia of speech* instead. They reported 13 speech characteristics presented by children with CAS, some of which were similar, and others dissimilar,

to those of acquired apraxia of speech (AOS). In addition, these authors advised differentially diagnosing between CAS and traditional articulation disorders and suggested that the treatment of these two disorders would differ (Rosenbek & Wertz, 1972). Other authors (for example: Ferry, Hall, & Hicks, 1975; Yoss & Darley, 1974a) also described the behavioural characteristics of children diagnosed with CAS from a motor programming perspective. However, another school of thought continued to favour the linguistic orientation and attributed the symptoms of CAS to a phonological, syntactic and/or general expressive language deficit (Aram, 1984; Bowman, Parsons, & Morris, 1984; Crary, 1984; Ekelman & Aram, 1983; 1984).

The linguistic and motor programming processes presumed to be impaired in CAS were poorly understood and described at the time. These initial reports did contribute towards greater awareness of a disorder that differs from dysarthria and what was traditionally considered functional articulation or developmental phonological disorders. However, the ambiguity in terminology used, and the theoretical understanding of the nature and symptoms of CAS, made it difficult for researchers and clinicians to effectively diagnose, treat and investigate the disorder. The controversy surrounding CAS that began in these early years prompted Guyette and Diedrich to label CAS as "a label in search of a population" (1981, p. 39). Early research concerns revolved around the uncertainty of the cause or underlying nature of CAS; the lack of agreement on the diagnostic symptoms of CAS; the diverse, often circular, criteria applied in selection of research participants; the poor definition of terms and variables; and methodological issues, such as the description of stimulus conditions and reliability of measurements used (Guyette & Diedrich, 1981).

Though it highlighted some critical areas in which the investigation of CAS needed to improve, Guyette and Diedrich's (1981) criticism of CAS as a clinical entity

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may have been somewhat prejudiced and they were perhaps reluctant at the time to envisage a concept such as apraxia of speech from a theoretical perspective. Despite the controversy surrounding the existence of CAS, researchers continued to investigate the disorder. The acceptance of CAS as a clinical entity grew as more research emerged, as the quality of research became more refined in terms of the methodology implemented, and as our theoretical conceptualisation of the process of speech sensorimotor control grew. Clinicians continued to identify among their clients certain children who presented with speech production difficulties which were more appropriately diagnosed as CAS. Research in the 1990's and 2000's mainly focussed on exploring the salient features of CAS in an attempt to establish a list of diagnostic criteria (Ball, Bernthal, & Beukelman, 2002; Davis, Jakielski, & Marquardt, 1998; Davis & Velleman, 2000; Forrest, 2003; Shriberg, Green, Campbell, McSweeny, & Scheer, 2003; Shriberg, Aram, & Kwiatkowski, 1997b; Thoonen, Maassen, Gabreëls, Schreuder, & de Swart, 1997). In addition, various authors sought to clarify the theoretical explanations of the underlying nature of CAS (Hall, Jordan, & Robin, 1993; Love, 2000; Marquardt et al., 2002; Shriberg, Aram, & Kwiatkowski, 1997a; Strand & Skinder, 1999). As a result, a wide range of diagnostic criteria and theoretical explanations were proposed, but little agreement existed between the different schools of thought.

In 2007, ASHA addressed some of the issues surrounding the nature and identification of the disorder in their technical report on CAS. In this report, the authors recommended that the term *childhood apraxia of speech* be used to label the disorder, as opposed to *developmental apraxia of speech* or other alternative terms which were used earlier (ASHA, 2007). Also, a working definition was proposed and a number of characteristic features of CAS were identified by the

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ASHA committee. They reported that the majority of commonly cited CAS symptoms tend to be more consistent with a deficit in motor planning and/or programming of speech movements than with a linguistic deficit (ASHA, 2007). The ASHA technical report has, to some extent, contributed to greater comparability across research studies.

A consequence of the ambiguity surrounding CAS is that relatively little research on the treatment of CAS was conducted prior to 2007 (ASHA, 2007). General treatment suggestions were made (Davis & Velleman, 2000; Rosenbek, Hansen, Baughman, & Lemme, 1974; Strand & Skinder, 1999; Yoss & Darley, 1974b) and were often based on methods used in the treatment of adult AOS. Isolated articles reported on the application of specific approaches (for example: Culp, 1989; Krauss & Galloway, 1982; Rosenthal, 1994; Strand & Debertine, 2000), though the level of evidence generated was low and theoretical justification of these approaches was typically superficial. The ASHA technical report on CAS (ASHA, 2007) and a Cochrane review (Morgan & Vogel, 2008) highlighted the dearth in high-level research evidence on theoretically-founded treatment of CAS. An increase in the number of treatment studies has subsequently been observed in the literature on CAS and will be discussed in a later section.

2.2. Defining childhood apraxia of speech

The definition of a speech disorder tends to reflect the particular definers' view of the disorder (Hall et al., 2007). ASHA state that definitions of CAS should comprise three components: "description of the core problem, attribution of its cause or etiology, and listing of one or more diagnostic signs or markers" (2007, p. 4). Given the wide-ranging theoretical conceptualisations of CAS, it is not surprising that numerous

definitions of CAS have been put forward in the literature. These definitions typically differ in terms of the first component, that is, whether authors view the core deficit as a disorder in perception (input processing) and/or production (output) and whether they attribute it to the level of linguistic representation or motor planning and/or programming of speech production (ASHA, 2007; Hall et al., 2007).

After compiling a list of more than 50 definitions found in the literature, the ad hoc committee on apraxia of speech in children proposed the following working definition for CAS (ASHA, 2007, p. 3-4):

> "(CAS) is a neurological childhood (pediatric) speech sound disorder in which the precision and consistency of movements underlying speech are impaired in the absence of neuromuscular deficits (e.g. abnormal reflexes, abnormal tone). CAS may occur as a result of known neurological impairment, in association with complex neurobehavioural disorders of known or unknown origin, or as an idiopathic neurogenic speech sound disorder. The core impairment in planning and/or programming spatiotemporal parameters of movement sequences results in errors in speech sound production and prosody."

The above definition represents some resolution to the debate that has clouded the history of CAS as a clinical entity.

3. Salient features of CAS

As mentioned earlier, the majority of research on CAS has centred on exploring the salient or characteristic symptoms of the disorder in an attempt to identify a diagnostic marker or an agreed-upon list of diagnostic features. Perceptual, acoustic and kinematic measures of a number of features have been investigated. The lack of agreement on the criteria of CAS used in participant selection, the heterogeneity of children presenting with CAS and the co-occurrence of other disorders in research

participants have created significant barriers to determining the underlying nature of CAS and those symptoms which accurately differentiate CAS from other speech sound disorders (ASHA, 2007; Davis et al., 1998; Forrest, 2003). In addition, circularity issues and inconsistent control comparisons have also hindered the generalisability of research findings (ASHA, 2007; Guyette & Diedrich, 1981; Hall et al., 2007). As a result, there is currently no validated list of symptoms to diagnose CAS. Along with the proposed working definition for the disorder, the ASHA technical report committee identified three characteristics that are generally considered key features of CAS (ASHA, 2007). These three characteristics "are consistent with a deficit in planning and programming of movements for speech" (ASHA, 2007, p. 4). The three key characteristics are "(a) inconsistent errors on consonants and vowels in repeated productions of syllables or words, (b) lengthened and disrupted coarticulatory transitions between sounds and syllables, and (c) inappropriate prosody, especially in the realization of lexical or phrasal stress" (ASHA, 2007, p. 4). However, clinicians and researchers are explicitly cautioned that these three features may not be "the necessary and sufficient signs of CAS" (ASHA, 2007, p. 4). The presence of other CAS features should also be considered in the diagnosis of the disorder.

Below is a list of commonly cited speech (segmental), prosodic (supra-segmental) and other characteristics of CAS. The list is primarily compiled from the ASHA technical report (2007, p. 3-4, 16-23), Hall et al. (2007, p. 15-52) and Shriberg, Lohmeier, Strand, and Jakielski (2012, p. 453), but additional studies which have reported or investigated a specific characteristic are also indicated.

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3.1. Speech (segmental) characteristics

- Reduced phonetic inventory (Crary, 1984; Davis et al., 1998).

- Inconsistent articulation across repeated productions of the same utterance (Betz & Stoel-Gammon, 2005; Bowman et al., 1984; Marquardt, Jacks, & Davis, 2004; Nijland et al., 2002; Shriberg et al., 1997b).

- Frequent omission errors (Jacks, Marquardt, & Davis, 2006; Nijland et al., 2002; Rosenbek & Wertz, 1972; Shriberg et al., 1997a).

- Distortions and distorted substitutions of consonants (Jacks et al., 2006; Rosenbek & Wertz, 1972; Yoss & Darley, 1974a).

- Vowel distortions and substitutions (Davis, Jacks, & Marquardt, 2005; Pollock & Hall, 1991; Smith, Marquardt, Cannito, & Davis, 1994; Walton & Pollock, 1995).

- Voicing errors (Lewis, Freebairn, Hansen, Iyengar, & Taylor, 2004; Van der Merwe & Grimbeek, 1990; Yoss & Darley, 1974a).

- Lengthened and disrupted coarticulatory transitions between sounds and syllables (including difficulty with initial articulatory configurations and syllable segregation) (Lewis et al., 2004; Maassen, Nijland, & van der Meulen, 2001; Nijland et al., 2003; Nijland et al., 2002; Shriberg et al., 2003).

- Unusual errors that "defy process analysis" (for example: addition of sounds, initial consonant deletion) (Lewis et al., 2004; Peter, Button, Stoel-Gammon, Chapman, & Raskind, 2013; Shriberg, Aram, & Kwiatkowski, 1997c).

- Increased errors on longer, more complex utterances (Crary, 1984; Davis et al., 1998; Shriberg et al., 1997a; Yoss & Darley, 1974a).

3.2. Prosodic (supra-segmental) characteristics

- Inappropriate lexical stress (for example: excessive-equal stress across syllables in words or sentences) (Ballard, Robin, McCabe, & McDonald, 2010; Davis et al., 1998; Munson, Bjorum, & Windsor, 2003; Peter & Stoel-Gammon, 2005; Shriberg et al., 1997b; 1997c; Skinder, Connaghan, Strand, & Betz, 2000).

- Errors in rate (for example: slow rate, variations in rate) (Davis et al., 1998; Shriberg et al., 2003; Yoss & Darley, 1974a).

- Variable nasal resonance (Bowman et al., 1984; Shriberg et al., 1997b; Stackhouse & Snowling, 1992b).

3.3. Other characteristics

- Nonspeech motor difficulties (oral apraxia, groping, impaired volitional oral movements, general clumsiness) (Crary, 1984; Davis et al., 1998; Rosenbek & Wertz, 1972; Yoss & Darley, 1974a).

- Language deficits (receptive language deficits, errors in morphology and syntax) (Ekelman & Aram, 1983; Lewis et al., 2004).

- Metalinguistic or literacy deficits (poor phonological awareness, reading and spelling difficulties) (Lewis et al., 2004; Marion, Sussman, & Marquardt, 1993; Marquardt et al., 2002; Stackhouse & Snowling, 1992a; Zaretsky, Velleman, & Curro, 2010).

From the preceding sections, it is clear that CAS is a complex and controversial childhood speech sound disorder. Uncertainty regarding the underlying nature and causes of the disorder, and a lack of differentially diagnostic features are among the

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key issues influencing research and clinical practice in this field. These issues have particularly influenced the development, application and investigation of theoretically-founded treatment approaches for CAS (ASHA, 2007; Morgan & Vogel, 2008; Murray et al., 2014). A review of the current state-of-the-art in CAS treatment research follows.

4. Treatment of CAS: A state-of-the-art review

Numerous approaches for the treatment of CAS have been suggested by different authors, based on their theoretical conceptualisation of the underlying nature of the disorder and its characteristic features. Treatment approaches for CAS have been categorised as motor, linguistic, a combination of motor and linguistic, or alternative and augmentative communication (AAC) approaches (ASHA, 2007; Hall et al., 2007; Murray et al., 2014). These approaches encompass a wide variety of treatment methods and procedures. While individual approaches usually have a particular focus or goal, most approaches tend to rely on several common principles of treatment. In the following sections, three approaches, which have received a great deal of attention in recent literature, are discussed and a brief description of other approaches is provided.

4.1. The Dynamic Temporal and Tactile Cueing (DTTC) approach

The Dynamic Temporal and Tactile Cueing (DTTC) approach was developed by Strand and her colleagues (Baas, Strand, Elmer, & Barbaresi, 2008; Strand & Skinder, 1999; Strand & Debertine, 2000; Strand, Stoeckel, & Baas, 2006). It is primarily an adaptation of integral stimulation (Rosenbek et al., 1973) for use with children with CAS (Strand & Skinder, 1999; Strand et al., 2006). The authors of

DTTC view CAS as a disorder in the planning and/or programming of movement parameters for speech, though they acknowledge that the specific processing skills which are actually impaired in CAS are difficult to determine (Strand & Skinder, 1999). They broadly propose that the treatment of CAS should target those parameters which are known to underlie the development of motor skills. They argue that DTTC, as a motor approach that is based on integral stimulation and the principles of motor learning (PML), allows this (Strand & Skinder, 1999). The approach is particularly recommended for very young children or those who have severe CAS (Maas et al., 2014; Strand et al., 2006).

In DTTC, the movements for articulation are shaped through imitation and the use of multimodal cues. The child initially produces target utterances simultaneously with the clinician, and is given visual, auditory, tactile and gestural cues as necessary. Rate of simultaneous production is slowly increased as the child becomes more accurate. Thereafter, the child directly imitates the clinician's auditory model and cues are reduced. Finally, the child imitates the clinician following a short delay. The timing (or 'temporal relationship') between the clinician's presentation of a stimulus and the child's response is dynamically varied during a session, depending on the child's success. Treatment stimuli typically include a small group of functional words with simple syllable structure (CV, VC, CVC, and CVCV). DTTC incorporates a number of principles of motor learning (Strand & Skinder, 1999; Strand & Debertine, 2000; Strand et al., 2006), including massed and distributed practice, high number of trial repetitions, blocked and random practice of targets (Maas & Farinella, 2012), and knowledge of performance feedback, which is gradually reduced (Maas, Butalla, & Farinella, 2012). According to Strand et al. (2006, p. 300), the DTTC

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approach "allows opportunity for the child to take increasing responsibility for assembling and retrieving motor plans with progressively less cueing."

4.2. The Rapid Syllable Transition Treatment (ReST) approach

Ballard, McCabe and colleagues (Ballard et al., 2010; McCabe, Macdonald-D'Silva, van Rees, Ballard, & Arciuli, 2014; Murray, McCabe, & Ballard, 2012; Thomas, McCabe, & Ballard, 2014) developed and investigated the Rapid Syllable Transition Treatment (ReST) approach. ReST is a relatively new approach to the treatment of CAS and was developed in response to the observation that few other treatments directly address inappropriate prosody (Ballard et al., 2010). This is despite the fact that inappropriate prosody is often cited as one of the key characteristics of the disorder (ASHA, 2007; Hall et al., 2007; Shriberg et al., 1997c; Shriberg et al., 2012). A key assumption underlying ReST is that inappropriate prosody, such as inaccurate lexical stress, is the result of "a deficit in rapid and fluent control of temporal and spatial parameters of articulator movement required to produce the fine variations in duration, vocal intensity, and F_0 across syllables" (Ballard et al., 2010, p. 1229).

ReST is a motor approach that uses intensive practice of multisyllabic nonwords with varying stress patterns, within the context of motor learning principles, to improve lexical stress in children with CAS. Speech sound accuracy and coarticulatory transitions between sounds and syllables are also targeted (Ballard et al., 2010; Murray et al., 2012). For treatment stimuli, a number of sounds (for which the child is stimulable) are combined to form complex multisyllabic nonwords with either strong-weak (SW) or weak-strong (WS) stress patterns. The complexity of stimuli is set at one level above the child's performance at assessment, and is defined by the number of syllables and the number of different sounds in nonwords.

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For example, the nonwords 'bataga, batigu, butagitu' represent an increase in complexity (Ballard et al., 2010; Murray et al., 2012; Thomas et al., 2014). During pre-practice, the clinician verbally and orthographically presents a sentence with the multisyllabic nonword at the end of a carrier phrase, and the child imitates the clinician. The clinician provides cues (for example: modelling, phonetic placement, visual cues and slow rate), as well as knowledge of performance (KP) feedback to shape accurate production. The child is given KP feedback on the use of vowel duration to indicate stress, normal speech rate with smooth transitions, and appropriate loudness. Once accurate production of five nonwords is achieved, the child practices 10 SW and 10 WS nonwords five times each in random order during the practice part of the session. Here, only delayed knowledge of results (KR) feedback on accuracy is given on 50% of trials (Ballard et al., 2010; Murray et al., 2012; Thomas et al., 2014). The specific PML applied in ReST – the use of a large number of practice trials, with complex and varied stimuli presented in random order, and reduced KR feedback – provide the opportunity for optimal generalisation and maintenance of newly learnt motor skills for accurate realisation of lexical stress (Ballard et al., 2010; Murray et al., 2012; Thomas et al., 2014). ReST is suitable for school-aged children with a mild to moderate severity of CAS, who are able to read the orthographically presented stimuli and whose speech sound production is not severely impaired (Maas et al., 2014).

4.3. *An Integrated Phonological Awareness approach*

The third treatment approach that will be discussed is a linguistic approach, specifically labelled as an integrated phonological awareness (IPA) approach (McNeill, Gillon, & Dodd, 2009a; McNeill, Gillon, & Dodd, 2009b; McNeill, Gillon, &

Dodd, 2010; Moriarty & Gillon, 2006). This approach is based on the theoretical notion that the underlying deficits in CAS are inadequate phonological representations, poor phonological planning, and unstable motor programs to direct speech production (Marquardt et al., 2002; Marquardt et al., 2004; McNeill et al., 2009b; Moriarty & Gillon, 2006). There are reports that children with CAS experience difficulties with phonological awareness, reading and spelling in addition to other typically reported speech symptoms (Lewis et al., 2004; Stackhouse & Snowling, 1992a; Zaretsky et al., 2010). It is, therefore, proposed in the IPA approach that targeting phonological awareness and early literacy skills during intervention may prevent these written language difficulties (McNeill et al., 2009b; Moriarty & Gillon, 2006). According to Gillon and her colleagues, the IPA approach also contributes to improved speech production in children with CAS as it facilitates the development of more specified phonological representations and more stable motor programs to guide speech (McNeill et al., 2009a; Moriarty & Gillon, 2006).

In the IPA approach, phonological awareness tasks are used to simultaneously target phoneme awareness, early literacy skills, and speech production. These tasks typically include phoneme-grapheme association, identification of phonemes in isolation and in word-initial and -final positions, phoneme segmentation and blending, and manipulation of orthographically presented phonemes (McNeill et al., 2009a; McNeill et al., 2009b; Moriarty & Gillon, 2006). A speech error pattern is selected from the client's assessment results (for example: /s/-cluster reduction) and is addressed in real word treatment stimuli (for example: "stop, spoon, step"). Targeted speech practice occurs within the context of phonological awareness activities. The client is expected to produce target words at least 15 times during a session. The clinician assists the client in identifying speech

errors when they occur, provides cues relating to the phonological elements of the sound or word and then prompts the client to correct the production. No articulatory-related feedback is provided. Once the selected error pattern is eliminated, another pattern is treated (McNeill et al., 2009a; McNeill et al., 2009b; Moriarty & Gillon, 2006).

The authors of the IPA approach urge clinicians to consider the risk of possible literacy difficulties in at least some children with CAS and highlight the value of a multi-faceted approach to the treatment of CAS (McNeill et al., 2009a; Moriarty & Gillon, 2006). However, given that children's linguistic and speech motor abilities develop concurrently and interactively (Smith & Goffman, 2004; Smith, 2006), it is uncertain whether the language deficits observed in some children with CAS are "primary deficits or flow-on effects from CAS, comorbid impairments, or perhaps compensatory behaviours" (Murray et al., 2014, p. 486). This approach may be implemented for pre-school and young school-aged children, with mild-moderate to severe CAS (Murray et al., 2014). Factors such as CAS severity, receptive language skills, non-verbal cognition and stimulability of target sounds may influence children's response to this intervention (McNeill et al., 2009a; Moriarty & Gillon, 2006).

4.4. Other treatment approaches

A brief description of several other approaches for CAS treatment and common intervention methods is provided here. The Prompts for Restructuring Oral Muscular Phonetic Targets (PROMPT) approach has been applied to the treatment of CAS for some time, and was recently investigated empirically (Dale & Hayden, 2013; Kadis et al., 2014). PROMPT is a motor-based, multi-sensory approach in which visual and auditory cues are combined with tactile, kinaesthetic, and proprioceptive cues on the

child's face to train speech movements (Dale & Hayden, 2013; Square, Namasivayam, Bose, Goshulak, & Hayden, 2014). The approach is based on the Motor Speech Hierarchy (Hayden & Square, 1994, as cited in Dale & Hayden, 2013), a seven stage model of the development and motor control of the speech subsystems. The hierarchy guides the assessment of a client and the selection of treatment priorities (Dale & Hayden, 2013; Square et al., 2014). In addition to multimodal prompts, which represent KP feedback that is gradually faded, PROMPT initially applies mass practice of trained items, followed by distributed, random practice in the context of functional activities (Dale & Hayden, 2013).

Other primarily motor-based approaches to CAS treatment include: articulation with facilitative vowel contexts (Stokes & Griffiths, 2010); combined intraoral stimulation and articulatory training with electropalatography (Lundeborg & McAllister, 2007); combined melodic intonation therapy and the touch-cue method (Martikainen & Korpilahti, 2011); and rate control therapy (Rosenthal, 1994). The approaches focus on articulation and/or prosodic accuracy as outcome measures and implement phonetic placement, imitation, multimodal cues and PML as treatment strategies. In addition, Preston, Brick, and Landi (2013) have evaluated the use of ultrasound biofeedback combined with traditional articulatory therapy in training different sound sequences in older children with CAS.

In many treatments for CAS, there has been a trend of implementing PML as key treatment strategies and attributing the improvements observed to the use of these principles (for example: Ballard et al., 2010; Dale & Hayden, 2013; McCabe et al., 2014; Strand & Debertine, 2000; Strand et al., 2006). Several authors have also investigated the influence of specific PML in CAS treatment, in order to determine which principles promote optimal speech motor learning. The specific PML which

have been investigated are practice amount (production frequency) (Edeal & Gildersleeve-Neumann, 2011), practice schedule (Maas & Farinella, 2012; Skelton & Hagopian, 2014), and feedback frequency (Maas et al., 2012). Edeal and Gildersleeve-Neumann (2011) found that a large practice amount or high production frequency lead to greater speech production gains and better generalisation than a low production frequency for both children in their study. Two studies have investigated the influence of practice schedule in CAS treatment and found that that some children with CAS demonstrate greater treatment and generalisation effects with a random practice schedule (Maas & Farinella, 2012; Skelton & Hagopian, 2014), while others benefit more from a blocked schedule (Maas & Farinella, 2012). Similarly, Maas et al. (2012) observed better treatment gains for two children in the reduced feedback frequency condition, while one child showed an advantage in the high feedback frequency condition. In addition, research suggests that children with CAS benefit significantly from variable practice (Edeal & Gildersleeve-Neumann, 2011; Skelton & Hagopian, 2014).

A number of other intervention methods are commonly applied across the different CAS treatment approaches. These methods include repetitive and intensive drill work (for example: Ballard et al., 2010; Edeal & Gildersleeve-Neumann, 2011; Strand et al., 2006), the use of integral stimulation (for example: Edeal & Gildersleeve-Neumann, 2011; Maas & Farinella, 2012; Strand & Debertine, 2000) and the use of multimodal cueing which is gradually reduced (for example: Dale & Hayden, 2013; Maas et al., 2012; Martikainen & Korpilahti, 2011; Strand et al., 2006).

There are also treatment approaches which can be considered primarily linguistic, these are: combined stimulability training protocol and modified core

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vocabulary training (Iuzzini & Forrest, 2010); melodic intonation therapy with traditional therapy (Krauss & Galloway, 1982); aided AAC modelling (Binger & Light, 2007; Binger, Kent-Walsh, Berens, Del Campo, & Rivera, 2008; Binger, Maguire-Marshall, & Kent-Walsh, 2011); and computer-based AAC (Harris, Doyle, & Haaf, 1996). Though some motor cues or AAC systems were implemented, the outcomes measures of these approaches were mostly linguistic in nature. Lastly, AAC approaches that have been applied in the treatment of CAS include the use of a voice output device as alternative communication (Bornman, Alant, & Meiring, 2001) and the partners in augmentative communication training (PACT) approach (Culp, 1989).

From the above review of the literature on CAS treatment, it is apparent that numerous approaches are available. However, in line with current evidence-based practice principles, it is necessary to critically evaluate the methods of these various approaches, as well as the research supporting them.

5. A critical evaluation of the state-of-the-art in CAS treatment

As a critical evaluation of the current state-of-the-art in CAS treatment, the evidence generated by research on these approaches, the treatment methods and strategies implemented, and the selection of treatment targets will be reviewed.

The ASHA (2007) technical report on CAS found that, prior to 2007, the majority of CAS treatment evidence was derived from expert opinion (Level IV evidence) and non-experimental case studies (Level III evidence). Similarly, a systematic review published by the Cochrane Collaboration reported that few approaches are supported by high-level research evidence; specifically, no randomised or non-randomised controlled studies (Level Ib or IIa evidence) exist

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(Morgan & Vogel, 2008). The Cochrane review concluded that there is "a critical lack of well controlled treatment studies addressing treatment efficacy for CAS" (Morgan & Vogel, 2008, p. 2). Since this review, there has been an increase in the number of well-designed controlled studies (Murray et al., 2014). In the most recent review on CAS treatment research, Murray et al. (2014) report that, in terms of the phase of research, investigations on the different CAS treatments are either in Phase I or Phase II. The highest level of evidence available for CAS treatment is currently Level IIb evidence, in the form of SCED studies. These authors reviewed the CAS treatment literature from 1970 to 2012 and identified 13 different treatment approaches which are supported by Level IIb evidence. Of these 13 approaches, three met the criteria for preponderant evidence, using Smith's (1981) level of certainty hierarchy: the Dynamic Temporal and Tactile Cueing (DTTC) approach, Rapid Syllable Transition Treatment (ReST), and the integrated phonological awareness (IPA) approach. The research supporting these three approaches comes from SCED studies, with moderate to high confidence in CAS diagnosis and replication across several participants. Also, these studies report statistically positive treatment, generalisation and/or maintenance effects (Murray et al., 2014). The remaining 10 approaches supported by Level IIb studies were considered suggestive evidence, because the study design, CAS diagnosis or treatment outcomes did not meet all the criteria for preponderant evidence (Murray et al., 2014).

The DTTC approach and the IPA are two of the few treatment approaches, identified in the review by Murray et al. (2014), which are supported by replicated studies. DTTC has been applied to the treatment of 13 children with CAS across six studies (Baas et al., 2008; Edeal & Gildersleeve-Neumann, 2011; Maas et al., 2012; Maas & Farinella, 2012; Strand & Debertine, 2000; Strand et al., 2006), while

altogether 15 children across four studies have received IPA treatment (McNeill et al., 2009a; 2009b; 2010; Moriarty & Gillon, 2006). The ReST approach has been replicated in three published studies with a total of 11 children receiving this treatment (Ballard et al., 2010; McCabe et al., 2014; Thomas et al., 2014). A few other approaches demonstrate some replication across participants (for example: Dale & Hayden, 2013; Iuzzini & Forrest, 2010; Preston et al., 2013), but not across more than one study.

Varied treatment (*acquisition*) effects are reported in studies investigating the different approaches to the treatment of CAS. For example: Strand and her colleagues (Baas et al., 2008; Strand & Debertine, 2000; Strand et al., 2006) report that five out of the six participants across their three studies showed an improvement on all or some treated utterances following DTTC treatment, while one participant did not respond to the treatment. Both children with CAS in Edeal and Gildersleeve-Neumann's (2011) study demonstrated a positive response to treatment, with better responses on items treated in the high production frequency condition. In their comparison of blocked versus random practice in DTTC treatment, Maas and Farinella (2012) observed an improvement on treated items for three of the four participants. Two participants favoured the blocked condition, while the third responded better to random practice. Three out of four participants also demonstrated treatment effects in the investigation of feedback frequency in DTTC by Maas et al. (2012). One participant from each of the latter two studies did not show a clear response to treatment (Maas et al., 2012; Maas & Farinella, 2012).

Ballard et al.'s (2010) first study investigating ReST included three participants with CAS and reported large treatment effects for each child. In a second study, which considered the influence of using orthographically biased

nonwords on the treatment of CAS using ReST, all four participants demonstrated positive treatment effects in terms of perceptual accuracy on treated items (McCabe et al., 2014). Thomas et al. (2014) found that a lower dose of ReST (twice a week for six weeks) resulted in similar treatment gains for all four participants as the typical dose (four times a week for three weeks). Moderate treatment effects have been reported for IPA treatment, with two out of three (Moriarty & Gillon, 2006) and nine out of 12 participants (McNeill et al., 2009b) demonstrating improvements in targeted speech and phonological awareness skills.

While clear treatment effects have been demonstrated in most studies, greater diversity is seen in the *generalisation* effects of the various CAS treatment approaches. The treatment gains observed in Strand and her colleagues' investigations of DTTC treatment (Baas et al., 2008; Strand & Debertine, 2000; Strand et al., 2006) showed little or no generalisation to untreated utterances. Edeal and Gildersleeve-Neumann (2011) report moderate generalisation of treated sounds to untreated probe words in the high production frequency condition, but smaller generalisation in the low production frequency condition. Some participants in the studies by Maas and colleagues demonstrated small generalisation effects for untreated items which were similar to treatment targets, yet others showed no such generalisation (Maas et al., 2012; Maas & Farinella, 2012).

In the investigations of ReST treatment, Ballard et al. (2010) found that treatment effects generalised to untreated nonword exemplars and less complex nonwords, but minimal generalisation to untreated real words or more complex nonwords was observed. Generalisation varied among the four participants in McCabe et al.'s (2014) study; three out of four participants showed generalisation to untreated related items, while one participant did not. A small amount of

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generalisation to connected speech was observed for all participants (McCabe et al., 2014), though this varied across the participants and the measures used (percentage consonants correct, percentage vowels correct and stress matches). Thomas et al. (2014) reported that treatment effects of the lower dose ReST generalised to untreated related items for two of the four participants and to untreated real words for all four participants in their study. Generalisation effects of IPA are mixed. Moriarty and Gillon (2006) observed generalisation of IPA treatment effects to untrained phonological awareness, letter-sound and nonword reading tasks for two out of three participants. McNeill, Gillon and Dodd (2009b) found that the speech gains achieved during IPA treatment were generalised to connected speech for nine out of 12 participants, while eight children generalised at least one improved phonological awareness skill to novel tasks. Some children did not demonstrate generalisation effects.

With regard to *maintenance* effects, the participant in Baas et al. (2008), both participants from Edeal and Gildersleeve-Neumann (2011) and two of the four children from Strand et al. (2006) demonstrated maintenance of all or some treatment gains for two to four weeks post-treatment. Maintenance effects for the remaining seven children who responded to DTTC treatment are either not reported or limited. Children who received ReST treatment appear to demonstrate good maintenance effects: 10 out of the 11 children across the three ReST studies maintained their improved skills for four weeks (Ballard et al., 2010; McCabe et al., 2014) or four months (Thomas et al., 2014). Similarly, for the IPA approach, McNeil et al. (2010) report that, as a group, the 12 participants from their 2009 study maintained their improved phonological awareness skills six months post-treatment.

The treatment approaches discussed above resulted in improvements in items targeted in *treatment*, while *generalisation* to untreated items and *maintenance* of skills varied across participants and outcomes measures. Factors which influence the outcomes of treatment include the treatment methods or strategies, as well as the types of targets selected for intervention. The methods or strategies involve the "how" of practice and learning, while the types of treatment targets relate to the "what" of practice (Maas et al., 2014, p. 199). Upon evaluation of the various treatment approaches proposed for CAS, it was observed that, in discussing their findings, most authors attribute the improvements achieved by participants to the methods or strategies employed in the particular treatment approach. Comparatively little theoretical consideration is given to the selection of targets and the influence this has on treatment, generalisation and maintenance effects.

In their selection of treatment stimuli, researchers and clinicians typically target functional or meaningful real words, in isolation or in phrases, primarily for their motivational value (Dale & Hayden, 2013; Iuzzini & Forrest, 2010; Martikainen & Korpilahti, 2011; McNeill et al., 2009b; Strand & Debertine, 2000; Strand et al., 2006). A few authors have advocated for the use of nonwords, particularly in the treatment of inappropriate prosody (Ballard et al., 2010; McCabe et al., 2014). Stimuli usually contain only those speech sounds which are in error, or a combination of error sounds and sounds which the child can produce. Furthermore, a variety of syllable structures are targeted simultaneously. However, generalisation of speech production gains to untreated items or to different contexts has often been limited or unpredictable (for example: Baas et al., 2008; Maas et al., 2012; Maas & Farinella, 2012; McNeill et al., 2009b; Moriarty & Gillon, 2006). One possible

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explanation may be that the influence of the type of stimuli, target sounds and syllable structure on generalisation and maintenance of skills is not always adequately considered from a theoretical perspective.

The treatment approach investigated in the current study is based on a comprehensive speech motor planning and programming model (Van der Merwe, 1997; 2009) which provides guidelines for treatment targets in particular, but also for treatment strategies (methods). The SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) aims to gradually expand the phonetic inventory of each individual child with apraxia and to facilitate the coarticulation of each sound with other sounds in controlled phonetic environments. Contrary to most other treatment approaches, sounds with the greatest ease of production are targeted first. To achieve the aim of improved speech motor planning and programming ability, nonwords are primarily used as treatment stimuli, but real words containing target sounds and syllable structures are also introduced from the start of treatment. In the following sections the theoretical model which informs the SML approach will be explained together with the rationale for treatment stimuli and strategies as derived from this model.

6. The four level framework of speech sensorimotor control and the characterisation of CAS from this perspective

A clinician's understanding of the underlying nature of speech disorders plays an important role in assessment, diagnosis, and selection of appropriate treatment methods (Hall et al., 2007). This is particularly true in the case of CAS. Several of the behavioural symptoms of CAS are similar to, and easily confused with, those of other speech sound disorders in children (ASHA, 2007; Hall et al., 2007). As discussed

earlier in this chapter, the underlying nature of CAS is not quite clear and it is necessary to look to models of speech production to better understand the nature of the disorder and to guide treatment.

Past research and clinical practice centred on understanding apraxia of speech in its developmental and acquired forms within a traditional three level framework of speech production. The levels were said to include linguistic encoding of the message, motor programming and motor execution (Darley, Aronson, & Brown, 1975). The attribution of specific processes to each level was, however, at times unclear. For example, there was a tendency to view speech motor planning as either occurring at the level of linguistic planning (that is, phonological planning), or as the equivalent of motor programming (Van der Merwe, 1997; 2009). This may explain why disagreement still exists regarding the actual processes that constitute phonological planning, motor planning and motor programming, and subsequently, the core deficit of CAS.

Van der Merwe (1997; 2009) proposes a distinction between linguistic-symbolic planning (which includes phonological planning), motor planning and motor programming in her theoretical framework for the characterization of pathological speech sensorimotor control. This distinction results in a four-level framework. The four levels are linguistic-symbolic planning, motor planning, motor programming, and motor execution. The specification of these levels is based on insight from neurophysiological findings on motor control, particularly the different neural structures involved in each level of the speech production process

The first level in the model, *linguistic-symbolic planning*, is a non-motor process, which entails the compilation of a message according to the semantic, syntactic, lexical, morphological and phonological rules of the speaker's language.

This message is then transformed by cortical motor areas into a form that the motor system can utilize. *Motor planning* involves "formulating the strategy of action by specifying motor goals" for the movement of articulators (Van der Merwe, 2009, p. 8). Thereafter, more detailed, muscle-specific motor program specifications in terms of tone, direction, range and velocity of movement are specified during *motor programming*. Lastly, the planned and programmed movements are *executed* and speech is produced (Van der Merwe, 1997; 2009).

Within the context of Van der Merwe's four-level framework, apraxia of speech is conceptualized primarily as a disorder in motor planning. Motor programming may however, be secondarily compromised (Van der Merwe, 2009; 2011). The detail within the four-level framework aids one in understanding the nature of apraxia of speech as it provides an account of normal motor planning and distinguishes it from phonological planning and motor programming (Van der Merwe, 1997; 2009). During typical speech development, young children develop the various skills involved in sensorimotor control of speech. From the perspective of the four level framework, motor planning of speech does not develop appropriately in the child with CAS. The core deficit of CAS is proposed to be an "inability to learn and control all the parameters of motor planning" (Van der Merwe, 2009, p. 14). This conceptualization predicts many of the characteristic speech signs of CAS. In the following paragraphs, motor planning of speech will be described as it relates to the characterisation of CAS from the perspective of Van der Merwe's (1997; 2009) four level framework of speech sensorimotor control.

The four-level framework (Van der Merwe, 1997; 2009) proposes that during motor learning of speech, a core motor plan is acquired for each speech sound of the language and this plan is presumably stored in the sensorimotor memory. The

assumption is that children should learn the core motor plan for each sound in their language and be able to correctly recall the plan for each sound that occurs in a word. An incomplete phonetic repertoire (ASHA, 2007; Davis et al., 1998; Forrest, 2003), as well as omissions and distortions of consonants (Jacks et al., 2006; Rosenbek & Wertz, 1972) and vowel errors as they occur in CAS (Davis et al., 2005; Pollock & Hall, 1991), may be the result of inadequate learning or recalling of core motor plans. A child must acquire the ability to identify the different motor goals within a core motor plan, to specify the temporal and spatial movement parameters for concurrent movements for the production of a sound (interarticulatory synchronisation) and sequence these movements for consecutive movements in an utterance. The ability to synchronise the movements of different articulators, and to coarticulate different combinations of movements, must be learnt. The child must also learn to adapt the core features of the motor plan to different phonetic environments and to "keep the adaptation of movements within the limits of equivalence and to ensure that the critical acoustic configuration be reached" (Van der Merwe, 2009, p. 7). Incorrect specification of motor goals may result in distortions or perceived substitutions of consonants or vowels. An individual needs to learn predictive control of movement outcomes, in which the motor plans and adaptations are centrally compared to an efference copy before execution of the movements (Van der Merwe, 1997; 2009). If the child has difficulty with interarticulatory synchronisation, errors in voicing or nasalisation may be evident. Difficulty "achieving initial articulatory configurations" (Shriberg et al., 2012, p. 453) and disrupted coarticulatory transitions between sounds or syllables (ASHA, 2007; Maassen et al., 2001; Nijland et al., 2002) may arise when the child with CAS cannot plan the coarticulation of different movements and adapt the motor plan to different

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phonetic environments. Inconsistency across repeated productions (Betz & Stoel-Gammon, 2005; Marquardt et al., 2004) can be attributed to an inability to *consistently* plan, adapt and centrally monitor temporal and spatial features which remain within the limits of equivalence from one production to the next.

In addition to the aspects involved in motor planning, the four-level framework suggests several hypothetical contextual factors which may influence the processes of speech sensorimotor control. These contextual factors include degree of automaticity of an utterance, syllable structure, familiarity, motor and linguistic complexity, speech rate, and length of the utterance (Van der Merwe, 1997; 2009). When applied to CAS, knowledge of the influence of contextual factors on motor planning may provide valuable guidelines regarding task complexity. For a child with CAS, some sounds in some phonetic contexts may be more demanding than others. Also, the four level framework predicts that longer, motorically more complex, self-initiated, and novel utterances will challenge speech motor planning (Van der Merwe, 1997; 2009). For example, in CAS, more errors occur on longer utterances (ASHA, 2007; Davis et al., 1998; Forrest, 2003; Shriberg et al., 2012), because the planning demands increase as utterance length increases (Van der Merwe, 1997; 2009).

Since the four-level framework comprehensively explains motor planning of speech and predicts the speech signs of apraxia of speech, it is able to provide guidelines for the treatment of the disorder in both its developmental and acquired forms (Ballard et al., 2000; Van der Merwe, 1997; 2009). In the next section, the SML treatment approach, which is based on the guidelines provided by the four level framework, will be described.

7. The speech motor learning (SML) approach

The speech motor learning (SML) approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) is theoretically based on the four level framework (Van der Merwe, 1997; 2009), which provides guidelines for treatment targets in particular, but also for treatment strategies (methods). The approach is a motor-based approach which "draws on evidence from motor control and speech motor control research, incorporates traditional articulatory-kinematic methods… utilizes motor learning principles… and graphic stimuli… and includes a focus on speech prosody" (Van der Merwe, 2011, p. 1175). The theoretical basis, methods and results of the SML approach have been published locally and internationally (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011). Phase I, proof of concept evidence is available from Van der Merwe (1985), while Phase II, Level III evidence is available from Schulze-Hulbe (2011) and Van der Merwe and Tesner (2000). The most recent systematic review on treatment in AOS (Ballard et al., 2015) rated Van der Merwe's 2007 study as Class IIIb evidence, and her 2011 publication on the SML approach as Class III evidence. These publications support the potential for further exploration of the SML approach. The following text provides an overview of the target selection procedures and the methods of the SML approach. More detail can be found in the above-mentioned references and on the website: www.apraxia-anitavandermerwe.co.za.

7.1 Overview of the methods of the SML approach

In the SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011), nonwords are implemented as primary treatment stimuli. The use of nonwords allows a focus on motor learning without interference from language-

mediating brain areas. Real words containing the target sounds and syllable structure are also incorporated from the start of treatment. Treatment commences with a group of target sounds, comprising three to four consonants (C) and four to five vowels (V), which are introduced simultaneously. A pre-treatment sound production assessment, in which all the sounds of a language are rated according to ease and accuracy of production, guides the selection of target sounds. Sounds with the greatest ease of production, from the client's perspective, are targeted first. As treatment progresses, *new sounds* (first Cs, then Vs) are systematically added to the already acquired group of sounds. Each addition of target sounds denotes a new *Stage* in the SML treatment. Treatment stimuli initially contain the CVCV (consonant, vowel, consonant, vowel) syllable structure, which later gradually progresses to CVC, CVCVC and CVCVCVC. These new syllable structures also denote new *Stages* in the SML treatment. Within each treatment Stage, the amount of phonetic variation across a series of nonwords is systematically increased from little variation between target sounds to more. This variation occurs hierarchically according to five variation levels (Van der Merwe, 2011). These levels are presented in the Table 1. Randomised variable practice is therefore achieved from the start of treatment, as several different sounds are targeted simultaneously in increasingly varied phonetic environments.

The procedures and stimuli described in the previous paragraph are guidelines for *target selection* that direct what should be practised and not just how. The *methods* (steps) of the SML approach (Van der Merwe, 1985; 2011) are as follows: The clinician may facilitate the initial production of target sounds in isolation and CV syllables in pre- practice, using integral stimulation and verbal cueing of the placement and movement of articulators. Imitative blocked practice of nonwords

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(three to five repetitions each), with integral stimulation and gradual fading of clinician cues, is then done. Following imitative practice, the client reads orthographically presented nonwords independently, as a form of self-initiated blocked practice. In young children who cannot read, only imitative practise of nonwords is done. A response delay of three to four seconds is imposed after rehearsal of some nonwords to facilitate self-initiated production. This is done after a nonword is produced correctly 80% of the time during blocked practice. The client is asked to remember the nonword, "think about it in his head" and then recall and produce the target nonword after the delay. Thereafter, series of nonwords are implemented as treatment stimuli and consecutive rehearsal of each nonword in a series occurs. Nonwords and series' are initially produced slowly, but rate of production is gradually increase until a normal speech rate is achieved by the client.

Table 1: Variation levels indicating the amount of phonetic variation across the sounds within a nonword series (Van der Merwe, 2011).

Phonetic variation level	Syllable structure *	Example of nonword series
Level 1	C1 V1 C1 V+	bibi, biba, bibo, bibe, bibu
Level 2	C1 V1 C2 V+	bimi, bima, bimo, bime, bimu
Level 3	C1 V1 C+ V1	bibi, bimi, biti, bini
Level 4	C1 V+ C2 V1	bima, boma, bema, buma
Level 5	C1 V+ C+ V+	bati, bome, buna, betu

* + indicates variation of the sound in that position of the CVCV series, C1 represents a consonant selected from the target set, C2 represents a second consonant from the target set.

Based on the guidelines which the four level framework provides regarding the influence of contextual factors, the SML approach (Van der Merwe, 1985; 2011) follows a continuum from least challenging to more challenging contexts. A progression occurs from easy to more difficult target sounds (from the client's

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perspective) and also from imitated to self-initiated practice, shorter to longer utterances, less variation in the phonetic environment to more variation, and slow to faster rates of production.

7.2. Application of principles of motor learning in the SML approach

The SML approach applies a number of principles of motor learning (PML) to promote optimal generalisation and maintenance of newly acquired motor planning skills. These PML are:

- *Blocked practice.* The child with CAS initially repeats each nonword three to five times in a "block."

- *Random practice.* Practice in the SML approach is random from the start of treatment because there is more than one target sound in a single nonword or real word. Practice gradually becomes more random in nature as consecutive rehearsal of nonwords in series' is done and as the order of sounds in nonwords becomes more variable.

- *Variable practice.* Variable practice is achieved as each target sound is rehearsed in changing phonetic contexts, and by systematically increasing the amount of phonetic variation within nonwords in a series and increasing rate of production of series'. During variable practice of each sound (as it occurs together with other sounds), plasticity in the core motor plan is facilitated and the individual systematically acquires the skill to coarticulate a specific speech sound with different other sounds. The plasticity in the motor plan of a sound and the ability to adapt it to different phonetic environments fosters the ability to generalise newly acquired skills to other phonetic environments and other contexts.

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- *High frequency of production or large practice amount.* Through intensive repetition, the client is given as many practice trials as possible.

- *Mental practice.* During the response delay, the client performs mental practice.

- *Target complexity*. Although treatment commences with easier sounds and syllables, stimuli are complex from the onset of treatment because multiple sounds are targeted simultaneously in varying coarticulatory environments.

- *Augmented feedback*. KP feedback is provided by the clinician during pre-practice to initially facilitate correct production of all sounds in a nonword. KR feedback is provided thereafter. Both types of feedback are provided initially after every production, but the frequency is gradually reduced to once every three to four productions. As this extrinsic feedback is reduced, the client's intrinsic feedback and self-monitoring skills are fostered.

8. The application of the SML approach to the treatment of CAS

Ultimately, a treatment approach should remediate the behavioural signs of apraxia by addressing the underlying deficit of the disorder. The SML approach aims to teach the child with CAS to learn and control the various aspects involved in motor planning of speech, culminating in more accurate speech production and increased intelligibility. A number of components within the SML approach contribute to its potential effectiveness in the treatment of CAS. The application of the SML approach is proposed to improve the following motor planning skills in children with CAS (Van der Merwe, 1985; 2011):

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- *The ability to learn, store and consistently recall core motor plans for the sounds of a language.*

The SML approach aims to guide the child with CAS in learning the core motor plans of a number of sounds and to enhance the recall of different core motor plans as required for any particular planned utterance. Movement parameters within core motor plans of the target sounds are taught in nonwords. Integral stimulation, imitation and cueing are used to facilitate the teaching of movement parameters. Intensive repetition of nonwords, achieved through blocked practice, presents the client with numerous opportunities to practice and habituate accurate planning of movement parameters in the core motor plan of each target sound. Through self-initiated blocked practice of nonwords, the SML approach develops the child's "ability to independently generate movements for speech production" (Van der Merwe, 2011, p. 1180). The child's phonetic repertoire is gradually expanded with each addition of new sounds to the corpus of already treated target sounds.

- *The ability to plan concurrent movements and sequence consecutive movements for different combinations of sounds in both short and long utterances.*

Speech comprises words made up of different combinations of sounds and syllables. The child with CAS must learn to recall and plan more than one core motor plan, and to sequence the temporal and spatial specifications for consecutive movements for different sound combinations. Planning of interarticulatory synchronisation of concurrent movements for the production of sounds, and coarticulation between consecutive movements, must also be

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improved. In the SML approach, target sounds in nonword stimuli are combined according to the phonotactic rules of the language, forming syllables and coarticulatory transitions similar to those in real words. By practicing sound combinations in the context of a variety of coarticulatory environments, the client develops the underlying ability to sequentially and concurrently organise the motor goals for consecutive sounds and syllables, and to plan the rapid transitions between them. Since a greater number of different sound combinations are possible with nonwords than with real words, nonwords offer greater variability in practice. In addition, sounds in nonwords can be combined in an unpredictable manner, creating a form of randomised practice. The randomised variable practice afforded by nonwords promotes flexibility in the motor planning system, generalisation of motor skills to other contexts (for example: real words) and maintenance thereof (Maas et al., 2008; Schmidt & Lee, 2005; Skelton & Hagopian, 2014). The progression from blocked to more random practice in treatment appears to promote greater generalisation than either blocked or random practice alone (Maas & Farinella, 2012; Porter & Magill, 2010). Real words containing target sounds are also introduced from the onset of treatment for generalisation and motivational purposes and are practiced in isolation, in phrases or in sentences.

The syllable structure of treatment stimuli in the SML treatment progresses in stages across time. In the initial stages, CVCV nonwords are targeted as the CV and reduplicated CVCV structures are typically acquired first in most languages (Jakobson, 1968). Nonword stimuli then progress in stages from CVCV syllable structure to CVC and later to CVCVC and

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CVCVCVC. The SML treatment may therefore be considered a hierarchical (Preston & Leaman, 2014) or "bottom-up" approach in that it develops "simpler speech movement patterns before progressing to more complex ones" (Maas et al., 2014, p. 200). Initially, blocked practice of individual nonwords is performed to facilitate the initial acquisition of the various motor planning skills. Thereafter, series of nonwords are implemented as treatment stimuli. Here, consecutive rehearsal of each nonword in a series occurs while varying rate of production. A series of utterances loads the motor planning task and requires the alternative production of various speech motor targets. The ability to do online planning of multiple, consecutive movements for longer utterances is thereby facilitated (Van der Merwe, 2011).

- *The ability to adapt the movement parameters within core motor plans according to phonetic contexts which are systematically varied, and to keep these adaptations within the critical acoustic boundaries.*

Through the systematic variation of the phonetic contexts in which each target sound occurs, the SML approach (Van der Merwe, 2011) aims to enhance the client's ability to accurately adapt the temporal and spatial movement parameters of core motor plans to different phonetic contexts and to changes in segmental duration. The ability to keep these adaptations within the critical acoustic boundaries for each particular sound and avoid distortion, by means of internal feedback, is also refined over time. Numerous opportunities are provided to practice this adaptation in progressively more varied coarticulatory environments as the client moves from one variation level to the next within each stage (Van der Merwe, 2011). Rate of production of nonword series' is

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also gradually increased to approach typical rate. An increase in rate also impacts temporal and spatial features of the motor plan and constitutes a different form of phonetic variation (Van der Merwe, 2011). This systematic variation of the phonetic contexts in which target sounds occur further contributes to the randomised and variable nature of practice mentioned earlier.

- *The ability to make use of internal feedback through central monitoring of motor plans before production.*

  The child with CAS must learn predictive control of the movement outcomes by centrally monitoring the plans and adaptations of movement parameters through internal feedback (Van der Merwe, 2011). In the SML approach, a three to four second response delay provides opportunity to mentally practice the movements for the sounds, promoting self-initiated recall of core motor plans from the sensorimotor memory and internal feedback of the planned utterance. Recall of the nonword after the response delay facilitates self-initiated production thereof (Van der Merwe, 2011).

9. Purpose of the current research

In light of the concerns surrounding the diagnosis of CAS and the current state-of-the-art in CAS treatment research, the need to investigate theoretically sound treatment approaches for CAS is clear. The purpose of the current study is to explore the effects of the SML approach (Van der Merwe, 1985; 2011) in the treatment of CAS. The SML approach is based on a comprehensive speech motor planning and programming model (Van der Merwe, 1997; 2009) that provides

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guidelines for treatment targets and treatment strategies (methods). This investigation is proposed as a single participant-based Phase II clinical research study (Robey, 2004; Wertz, 2002), in which the potential of the SML approach for treatment of CAS is examined empirically.

The primary purpose of the current study was to determine whether the SML treatment approach (Van der Merwe, 1985; 2011) would effect a positive change in the speech production of a child with CAS, as measured by whole word accuracy. By way of the various components incorporated in the SML approach (described earlier), this treatment is proposed to guide the participant in learning and controlling the different aspects of motor planning, which are believed to underlie the speech signs observed in CAS. The following research questions were posed:

1. Will treatment effects generalise to untreated non- and real-word stimuli containing only *treated* age-appropriate consonants and five vowels (Set 1 sounds, see Method)?

2. Will treatment effects generalise to untreated non- and real-word stimuli in addition containing three *untreated* age-appropriate consonants and the same five vowels (Set 2 sounds)?

3. Will treatment effects generalise to untreated non- and real-word stimuli in addition containing three *untreated age-inappropriate* consonants and the same five vowels (Set 3 sounds)?

CHAPTER 2: METHOD

1. Introduction to Chapter 2

The aim of the present study was to explore the effects of the SML approach (Van der Merwe, 1985; 2011) in the treatment of CAS. The study applied the SML approach to the treatment of a child with CAS and evaluated the effect of the treatment on the child's speech production, as measured by whole word accuracy. This chapter presents an explanation of the method followed in this investigation. The research aims and research design are described, followed by an explanation of the stimuli, procedures and data analysis.

2. Research aims

The primary aim of the current study was to determine whether the application of the SML treatment approach (Van der Merwe, 1985; 2011) would effect a positive change in the speech production of a child with CAS, as measured by *whole word accuracy*. The following sub-aims were formulated to achieve this primary aim:

1. To determine whether treatment effects would generalise to untreated non- and real-word stimuli containing only *treated* age-appropriate consonants and five vowels (Set 1 sounds).

2. To determine whether treatment effects would generalise to untreated non- and real-word stimuli in addition containing three *untreated* age-appropriate consonants and the same five vowels (Set 2 sounds).

3. To determine whether treatment effects would generalise to untreated non- and real-word stimuli in addition containing three *untreated age-inappropriate* consonants and the same five vowels (Set 3 sounds).

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3. Participant

3.1. Criteria for participant selection

The following criteria were used in the selection of the Participant:

- The Participant should be a child diagnosed with suspected CAS by an experienced speech-language therapist. The diagnosis of CAS should be based on the presence of a cluster of symptoms listed in current literature as characteristic of CAS. The list of symptoms (see Table 3) was compiled from ASHA (2007), Davis et al. (1998), Murray, McCabe, Heard, and Ballard (2015), Shriberg, Potter, Strand (2011), and Shriberg et al. (2012).

- The child should present with age-appropriate receptive language skills, as determined by the Rossetti Infant-Toddler Language Scale (Rossetti, 2006).

- The child should present with normal hearing abilities, as determined by a hearing screening test.

- The child should present with age-appropriate personal-social, perceptual-cognitive and self-help skills, as determined by the Developmental Assessment Schema (Anderson, Fowler, & Nelson, 1978) and clinical observation during a play-based assessment.

- The child should not present with any physical impairments, such as paralysis, paresis or involuntary movements of the oral structures or limbs or abnormal muscle tone; or structural abnormalities, such as cleft lip and/or palate. This will be determined by clinical observation.

3.2. Description of participant

The Participant selected for this study was a 33-month-old monolingual English-speaking boy, who was diagnosed with CAS by a speech-language therapist who has been working in the field of CAS and AOS for 40 years and has published internationally in this field. The CAS symptoms that he presented with are indicated in Table 2. Informal analysis of a 15-minute spontaneous speech-language sample revealed that he mostly made use of one- to two-word phrases, with considerably reduced intelligibility (35% words understood). His utterances consisted mainly of nouns and verbs, with V, CV, VC, VCV, CVCV and CVC syllable structure.

The Participant's phonetic repertoire comprised the following consonants, vowels and diphthongs: /p, b, t, d, m, n, w, h iː, ɪ, ɛ, æ, ə, ʌ, ɑ, ʊ, uː, ɔ, ɒ, əʊ, ɑʊ, ɪə, aɪ/. The *frequency of occurrence* ([number of correct productions of a specific sound ÷ total number of correct productions of all sounds] x100) and the *accuracy of production* ([number of correct productions of a specific sound ÷ number of opportunities for a specific sound] x 100) of sounds in spontaneous speech are presented in Table 3. A number of age-appropriate sounds (Bernthal, Bankson, & Flipsen, 2009; Shipley & McAfee, 2009) were absent in the Participant's speech (for example: /f, k, g, h/), suggesting a mildly reduced phonetic repertoire. His spontaneous speech exhibited distortions, distorted substitutions and omissions of many consonants. A large proportion of the consonant distortions comprised voice onset time errors and it was not always clear whether his production was voiced or voiceless for the bilabial plosives /b, p/ and the alveolar plosives /d, t/. He consistently produced the velar plosives /k, g/ as a voiceless velar fricative [x], which is not part of the typical English phonetic repertoire. Occasionally, he also replaced other consonants with this sound, though it was not always possible to determine

which consonant he was attempting to produce. Vowel and diphthong errors were also present in the Participant's speech. Some examples of his errors include: "doctor" produced as [dɒ_t̪ɑ], "good bye" as [tɔ_ baɪ], "there" as [dɛ_] and "my back's sore" as [maɪ tʌ_ _ tɔ_].

Inconsistency across repeated production of some consonants and vowels was observed. For example: "no" was produced as [nʌ, nəʊ, nɑʊ], and "mom" was produced as [mɒm, mɒ_, pⁿʌm], where there the initial sound of the third production evidenced a distorted [p] with elements of plosive and nasal release. These examples demonstrate the variable vowel quality observed, as well as inconsistent distortions, distorted substitutions and omissions of consonants. An increase in errors was observed on longer words or phrases, often making his utterance entirely unintelligible. The Participant occasionally presented with inappropriate pauses between sounds or syllables in words, for example: "foot" was produced as [pʊ_t̪s̪], with a pause before the /t/. This suggests that the Participant had mild difficulties with co-articulatory transitions between syllables. Since the Participant mainly used words with CV, VC, VCV and CVCV syllable structure, and simplified longer words to these structures, there was limited opportunity to further evaluate co-articulatory transitions. The Participant was also often unwilling to imitate a word or sound when prompted by his private speech-therapist or the researcher. An informal oral-facial examination revealed a mild difficulty in sequencing two to three consecutive oral movements with adequate accuracy and speed, possibly indicating a mild oral apraxia for these movements.

The Participant scored within his age range (33-36 months) for both the Language Comprehension and Language Expression subtests of the Rossetti Infant-Toddler Language Scale (RITLS) (Rossetti, 2006). Further formal testing was not

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conducted due to his young age. The Participant achieved most developmental milestones at the expected age; however, his early speech development was reportedly delayed. According to parental report, he was a quiet baby who demonstrated reduced babbling and few attempts to produce words. He suffered two incidents of acute idiopathic thrombocytopenic purpura (ITP) at the age of 13 and 22 months respectively. Treatment for ITP was successful and the Participant's parents did not observe any obvious signs of impact on his development.

The Participant was easily distracted during tasks and required regular prompting to refocus his attention and maintain his cooperation during therapy activities. Apart from the CAS and a short attention span, no other physical or cognitive difficulties were identified. The Participant's parents reported no difficulties with sucking, chewing or swallowing, though occasionally mild drooling was observed. No signs of paresis or involuntary movements of the oral structures or limbs were observed and muscle tone appeared normal. Structural deficits, such as cleft lip or palate were not present. The Participant demonstrated appropriate symbolic and imaginative play skills, as well as age-appropriate personal-social, perceptual-cognitive and self-help skills (Anderson et al., 1978). Formal hearing screening could not be conducted at the time, however, the Participant's parents reported that he responded appropriately to speech and non-speech sounds, and clinical observation did not indicate any hearing problems. The Participant had received early intervention (Rossetti, 2001) for approximately one year prior to his participation in the current study. Limited progress in terms of his speech production ability had been made.

Table 2. List of symptoms of CAS used in selection and diagnosis of the Participant, compiled from ASHA (2007), Davis et al. (1998), Murray et al. (2015), and Shriberg et al. (2012).

Symptom	Present?	Example*
Inconsistent or variable articulation of consonants and vowels across trial-to-trial repeated productions of the same word, syllable or sound	Yes	"no": /nəʊ/→ [nʌ, nəʊ, nɑʊ] "hop": /hɒp/ → [_ɒ_, _ɒp, _ɒtˈ]
Inappropriate co-articulatory transitions between sounds and syllables	Mild	"foot": /fʊt/ → [pʊ_ts̠] (limited opportunity to assess)
Inappropriate prosody, such as difficulties in the production of lexical or phrasal stress	No	
Reduced phonetic (consonant and vowel) repertoire	Yes	/f, k, g, h/: age-appropriate, but absent in Participant's speech
Vowel and diphthong errors	Yes	"back": /bæk/ → [tʌ_] "here": /hiəɹ/ → [jiæ_]
Consonant distortions	Yes	"this": /ðəs/ → [dɛs̠] "bunny" /bʌni:/ → [bʌdⁿi:]
Distorted substitutions of consonants	Yes	"mom": /mɒm/ → [pⁿʌm] "foot": /fʊt/ → [pʊ_ts̠]
Omission of consonants or vowels from words	Yes	"sit": /sət/ → [s̠ə_] "doctor": /dɒktɚ/ → [dɒ_t̪ɑ]
Error production increases with increased length of utterance	Yes	"Mom, pass my dudu": /mɒm pɑs mai dudu/ → [mɒ_ bæ_ bⁿai du_d̥i:]
Non-speech groping behaviours	No	
Voice onset time (VOT) errors	Yes	"daddy": /dædi:/ → [dæd̥i:] "too big": /tu: bɪg/ →/t̪u: b̥ɪx/
Intermittent hyper nasal resonance on production of speech sounds	No	
Difficulties in imitating sounds and words (poor stimulability) or reduced willingness to attempt imitation	Yes	
Substitution of verbal utterances with gestures	No	
Oral apraxia for sequential movements	Mild	Consecutively puff the cheeks and move the tongue left-to-right outside the mouth → Slow, inaccuracte movements with disrupted sequence.

* An underscore (_) represents an omission of a sound or an inappropriate pause between sounds or syllables.

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Table 3. Analysis of the Participant's speech: Frequency of occurrence (%) and accuracy of production (%) of consonants, vowels and diphthongs in words in spontaneous speech. The average ease of production ratings for each sound in isolation, obtained according to the guidelines of the SML approach (Van der Merwe, 1985; 2011) are also shown.

Consonants																									
	/p/	/b/	/t/	/d/	/k/	/g/	/m/	/n/	/ŋ/	/f/	/v/	/θ/	/ð/	/s/	/z/	/ʃ/	/ʒ/	/h/	/ʔ/	/tʃ/	/dʒ/	/w/	/l/	/ɹ/	/j/
Frequency of occurrence (%) *	11	20	14	16	0	0	21	4	0	0	0	0	0	0	0	1	0	3	0.5	1	0	7	0	0	1
Accuracy of production (%) *	58	76	61	57	0	0	79	75	0	0	0	0	0	0	0	67	0	44	100	67	0	82	0	0	40
Average ease of production rating **	1	1	1	2	4	4	1	2	4	2	3	4	4	4	4	3	4	4	3	4	4	3	4	4	2

Vowels / diphthongs / rhotics																					
	/i:/	/ɪ/	/ɛ/	/æ/	/ə/	/ʌ/	/ɑ/	/ʊ/	/u:/	/ɔ/	/ɒ/	/əɪ/	/əʊ/	/ɑʊ/	/iʊ/	/ɪə/	/aɪ/	/a:ɪ/	/ɔɪ/	/ɝ/	/ɚ/
Frequency of occurrence (%) *	8	3	14	7	1	15	4	7	7	15	7	0	4	2	0	3	3	0	0	0	0
Accuracy of production (%) *	90	64	82	89	60	87	90	94	94	89	100	0	63	71	0	43	75	0	0	0	0
Average ease of production rating **	1	1	1	1	2	2	1	1	1	1	1	2	2	2	4	3	1	1	1	4	4

* *Frequency of occurrence (%)* and *accuracy of production (%)* of sounds in words was obtained from the Participant's spontaneous speech sample.

** *Average ease of production rating* refers to the average of the three pre-treatment sound production assessment ratings for each sound in isolation (see *6.1 Selection of three sound sets* for explanation). Rating of 1: The sound was produced correctly all or most of the time (80% of attempts were correct); Rating of 2: The sound was usually produced correctly (at least 50% of attempts were correct); Rating of 3: The sound was usually produced incorrectly (20% of attempts were correct and some features of the sound were present and produced correctly); Rating of 4: The sound was consistently produced incorrectly or omitted, or no attempt was made to produce the sound.

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4. Ethical considerations

Ethical clearance for the study was obtained from the Research Ethics Committee of the Faculty of Humanities at the University of Pretoria (Appendix A). The researcher undertook to adhere to the ethical guidelines as outlined by the South African Speech, Language and Hearing Association (SASLHA) and the Health Professions Council of South Africa (HPCSA).

Informed consent was obtained from the Participant's parents (Appendix B), his private speech-language therapist (Appendix C) and the pre-school where treatment sessions were conducted (Appendix D). The Participant, his parents and private speech-language therapist were not obligated to participate and were free to terminate their participation at any time for any reason with no penalties. The Participant's assent was also obtained before the procedures commenced, by asking him whether he would like to play some games and say "funny" words. The researcher committed to being sensitive to the Participant's signs of fatigue or discomfort and permitted regular breaks during sessions.

5. Design

The study implemented a single-case experimental design, with multiple baselines and multiple probes across behaviours (Byiers et al., 2012; Kearns, 1986). The design resembles that used by Van der Merwe (2011) to determine the effect of the SML approach in treating AOS. To accommodate the principle of the SML approach to gradually expand the set of target sounds across treatment, a successive level analysis strategy (Kearns, 1986) was implemented. Three sets of sounds were identified in the current study. Only the consonants of Set 1 were treated (Sub-aim 1) together with five vowels which remained consistent across sets. Sets 2 (Sub-aim 2)

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and 3 (Sub-aim 3) each contained an expanded target consonant set. The additional consonants in Sets 2 and 3 acted as control behaviours. Generalisation to *untreated* nonwords and real words were probed in each set and acted as dependent variables. Generalisation to exemplars of treated nonwords of Set 1 acted as control for *response* generalisation (Ballard, 2001; Olswang & Bain, 1994), while generalisation to real words acted as control for *stimulus* generalisation (Ballard, 2001; Olswang & Bain, 1994).

Three baseline probes were performed on four different days over two weeks prior to the onset of treatment. The Participant received a total of eighteen 30-minute treatment sessions (9 hours) across nine weeks. A time-based criterion of nine weeks was applied to counter-act the possible influence of normal development on the outcomes of treatment. Repeated probes were performed once weekly across the treatment period. Thereafter, two follow-up probes were performed, at one week and two weeks post-treatment. The procedure followed in selecting the three sets of sounds and in compiling the treatment and probe stimuli are discussed in the following section.

6. Experimental stimuli

6.1. Selection of three sets of sounds

A pre-treatment assessment of sound production accuracy and stimulability of all English sounds was performed to determine which sounds the Participant found easier or more difficult to produce. Sounds were rated on three different days. On each of these days, the Participant was asked to produce four to five successive repetitions of verbally-presented consonants and vowels in isolation, while the first

and second authors made online judgements of the accuracy of production (see Table 3 for the average ease of production ratings). Consonants were rated first, followed by vowels. The same order of presentation was followed on all three days, though infrequent exceptions were made to maintain the Participant's cooperation. The following 4-point rating scale was implemented:

- Rating of 1: The sound was produced correctly all or most of the time (80% of attempts were correct);

- Rating of 2: The sound was usually produced correctly (at least 50% of attempts were correct);

- Rating of 3: The sound was usually produced incorrectly (20% of attempts were correct and some features of the sound were present and produced correctly);

- Rating of 4: The sound was consistently produced incorrectly or omitted, or no attempt was made to produce the sound.

The ratings of the accuracy of production and stimulability were then considered in the allocation of consonants to the three sets of behaviours probed in this study (see Van der Merwe, 2011 for a full description of the rating of sounds in the SML approach). Given the young age of the Participant, the assignment of sounds to each set was further guided by developmental norms for typical English speech sound acquisition (Bernthal, Bankson, & Flipsen, 2009; Shipley & McAfee, 2009), which indicate which sounds are age-appropriate at 33 months of age. The sound sets used in this study were as follows:

- *Set 1* sounds consisted of consonants (C) (/b, m, n, t/) that the Participant produced correctly on at least 80% of attempts (rated "1") and which are

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typically mastered before three years of age (within the range of 2;0 and 3;0 years). These consonants occurred in combination with five vowels (V) (/i, u, ɔ, ɛ, æ/) that were produced correctly on at least 80% of attempts. The five vowels remained consistent across all three sets.

- *Set 2* sounds consisted of Set 1 sounds (consonants and vowels) plus three additional consonants (/d, f, p/), which were produced correctly on at least 50% of attempts (rated "1" or "2") and which are typically acquired at three years of age (within the range of 2;6 and 3;6 years).

- *Set 3* sounds consisted of Set 1 and 2 sounds (consonants and vowels) plus three additional consonants (/l, s, v/), which were consistently produced incorrectly or omitted (rated "4") and which are typically mastered *after* three years of age (within the range of 3;0 and 5;0 years).

Following the allocation of sounds to the three sound sets, these sound sets were used in the compilation of treatment and probe stimuli.

6.2. Treatment stimuli

In the SML treatment approach, treatment commences with CVCV nonwords and later progresses to CVC and other more complex syllable structures. In the present study, only CVCV nonwords were used. A corpus of CVCV nonword treatment stimuli, containing Set 1 consonants (/b, m, n, t/) and the five vowels (/i, u, ɔ, ɛ, æ/), were compiled on all variation levels using the SML software program (downloaded from www.apraxia-anitavandermerwe.co.za). Examples of the treatment stimuli are presented in Appendix E.

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6.3. Probe stimuli

The probe stimuli implemented in this study comprised a list of *untreated* nonwords and real words with CVCV syllable structure. Three sets of probe stimuli were compiled to answer the sub-aims posed in this study: In order to answer *Sub-aim 1* (generalisation of treatment effects to untreated exemplars of treated behaviours), Set 1 probe stimuli comprised 10 untreated nonwords and seven real words containing only treated age-appropriate sounds. To answer S*ub-aim 2* (generalisation of treatment effects to other age-appropriate, but untreated consonants), Set 2 probe stimuli consisted of 10 untreated nonwords and 10 real words, each containing an untreated age-appropriate consonant. For *Sub-aim 3* (generalisation of treatment effects to untreated age-inappropriate consonants), Set 3 probe stimuli comprised 10 untreated nonwords and nine real words, each containing an untreated age-inappropriate sound. The non- and real-word probe stimuli of the three sets are presented in Table 4. When the available sounds limited meaningful CVCV combinations for real words, proper names and word approximations (for example, "dudu" for "sleep") were included if they were meaningful to the Participant.

7. Probe procedures

The first author conducted all probe sessions, either at the Participant's home, or at his private speech-language therapist's office. In total, 14 probe sessions were conducted over the duration of the study. First, three baseline probes (B1-B3) were performed on four different days over two weeks, prior to the onset of treatment. Repeated probes were performed once weekly across the treatment period of nine weeks (T1-T9 for Set 1, B4-B12 for Sets 2 and 3). Thereafter, two follow-up probes

Table 4. Target sounds, selected on the basis of stimulability and age-appropriate norms, and the corresponding nonword and real word probe stimuli for the three sound sets.

Set 1		Set 2		Set 3	
Target sounds: C: /b, m, n, t/ V: /i, u, ɔ, ɛ, æ/		Target sounds: C: /b, m n, t, d, f, p/ V: /i, u, ɔ, ɛ, æ/		Target sounds: C: / b, m, n, t, d, f, p, l, s, v/ V: /i, u, ɔ, ɛ, æ/	
Untreated nonwords	Untreated real words	Untreated nonwords	Untreated real words	Untreated nonwords	Untreated real words
/bibæ/	beanie	/bɔdu/	daddy	/bisu/	belly
/bubi/	Betty	/bifɛ/	"dudu"	/bɔvi/	loony
/bɔni/	Mannie	/dɔmɛ/	Daffy	/dilɔ/	Lulu
/mɛtæ/	many	/dɛni/	fatty	/dɔvɛ/	messy
/mɔtu/	nanny	/ditɔ/	meaty	/lubi/	movie
/næmɛ/	naughty	/fibɔ/	nappy	/lɛti/	Nelly
/nitɛ/	Tammy	/fumɛ/	penny	/sænɛ/	Sally
/tɛbɔ/		/fænu/	patty	/sɔtu/	seesaw
/tɔmu/		/pubæ/	teddy	/vimæ/	valley
/tænu/		/pætu/	tutu	/vɛnɔ/	

Note: Sounds were selected based on the pre-treatment accuracy of production and stimulability ratings. Target sound allocation was also guided by developmental norms for English speech sound acquisition (Bernthal et al., 2009; Shipley & McAfee, 2009). Vowels remained constant across sets. Newly introduced consonants are underlined. Only Set 1 sounds were treated. C = consonant, V = vowel.

(F1-F2 for Set 1, B13-B14 for Sets 2 and 3) were performed, at one week and two weeks post-treatment. Treatment and follow-up probes were administered on the same day each week and no treatment was provided on days on which probes were done. Each baseline and follow-up probe included all three sets of behaviours. During the treatment period, Set 1 stimuli were probed at every probe session (T1 through T9). After the fourth and fifth baseline probe sessions, Set 2 and 3 stimuli were probed at alternate probe sessions (B6, B8, B10, B12 and B7, B9, B11 respectively) to accommodate the Participant's attentional and motivational capacity.

Identical collection procedures were followed for all probe sessions. All probe items were imitatively elicited once, with fixed instructions to the Participant and no feedback on the accuracy of productions. First, the nonword stimuli from Set 1, 2,

and 3 were presented verbally to the Participant. Thereafter, the real words from each set were presented verbally with an accompanying picture. At the onset of the study, nonwords were shuffled within each set so that nonwords beginning with the same consonant were not all presented successively. The order of presentation of nonwords remained the same for all probe sessions, while that of real words occasionally varied to maintain the Participant's cooperation. Various play activities were incorporated in probe sessions to enhance the Participant's cooperation. All productions were recorded on a digital voice recorder (Olympus DM-450) and transferred to a laptop (Acer Aspire 3002WLCi) for later analysis. Care was taken to reduce or eliminate environmental and/or background noises, to ensure optimal quality of audio recordings.

8. Treatment procedures

The treatment procedures were implemented by the Participant's private speech-language therapist, under direct supervision of the researcher and the developer of the SML approach. The Participant received two 30-minute treatment sessions weekly for nine weeks. The treatment *steps* of the SML approach (Van der Merwe, 1985; 2011) which were implemented in the current study are presented in Table 5.

Usually, the SML steps also include orthographically presented stimuli, self-initiated blocked practice of nonwords, consecutive rehearsal of nonwords in a series and varying rate of production (see Van der Merwe, 2011 for a comprehensive discussion of the SML steps). However, during a trial session these steps were found to be inappropriate for the Participant, mainly due to his young age and cooperation level. For the duration of this study, real words were not treated due to

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the limited number of sound combinations forming meaningful words. Real words were therefore only used as probe items.

Table 5: The SML treatment steps (Van der Merwe, 1985; 2011) implemented in the study.

SML treatment step and brief description
Pre-practice
The clinician facilitated the production of target sounds in isolation and CV syllables, using integral stimulation ("look and listen") and verbal cueing of placement and movement of articulators. Knowledge of performance (KP) feedback was provided by the clinician during pre-practice to initially facilitate correct production of all sounds in a nonword. Once the criterion of correct production on 80% of attempts was reached for all target sounds, blocked practice was initiated.
Blocked practice of a nonword
The Participant was requested to repeat each nonword 3 to 5 times on imitation, with integral stimulation and verbal cueing when necessary. Visual prompts (e.g. holding up fingers, pointing to tokens) were used to indicate the first, second, etc. repetition and to encourage the Participant's cooperation. If the production of all the sounds in the first 3 repetitions of a nonword were correct, the clinician moved on to the next nonword. If not, the nonword was repeated up to 5 times, in an attempt to get 4 out of 5 (80%) correct productions before proceeding to the next nonword. Knowledge of results (KR) feedback was given, initially after every production, but the frequency was gradually reduced to once every three to four productions.
Response delay
A response delay of 3 to 4 seconds was imposed after correct production of some of the nonwords. The Participant was asked to remember the nonword, "think about it in his head" and then recall and produce the target nonword after the delay. KR was provided. If the nonword was produced incorrectly after the delay, blocked practice was again initiated and the participant received a second opportunity to produce the word after a delay. Internal monitoring of the planned utterance and self-initiated recall of movement parameters for target sounds was facilitated through this.

The steps implemented in this study (Table 5) were repeated with all nonwords within a variation level. Depending on the Participant's level of cooperation, approximately 10 to 25 nonwords were practiced in each treatment session. Treatment commenced with Set 1, variation level 1 stimuli and a criterion of correct production of all sounds in 80% of treatment stimuli had to be reached before

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moving to the next variation level. In the present study, the Participant completed variation levels 1 and 2 of Set 1.

9. Outcome measure analysis and description

All probe stimuli were perceptually analysed by consensus of two experienced listeners (the second and third authors), after repeated listening to the production of each probe stimulus. The order of presentation of probe sessions was randomized and analyses were done blind. The primary outcome measure used to answer the research questions, according to the sub-aims, was whole word accuracy (WWA) of untreated nonwords and real words. WWA was scored perceptually on a binary (correct or incorrect) scale. A word was judged as "correct" if all the sounds were produced accurately, with no distortions, substitutions, omissions, additions or trans-positioning. The different sounds in a nonword or real word had to be co-articulated well and with no inappropriate pauses between sounds.

10. Processing and analysis of the data

Raw scores of WWA were processed to obtain percentage WWA and data were then plotted for visual analysis (see Figures 1 to 3 in Chapter 3). Effect sizes (ES's) for WWA were calculated to determine the relative degree of the treatment effects (Beeson & Robey, 2006; Byiers et al., 2012; Gierut & Morrisette, 2011) and to supplement visual inspection (Maas & Farinella, 2012). ES's were calculated as follows (Beeson & Robey, 2006; Gierut & Morrisette, 2011):

$$ES = \frac{\textit{Mean of post-treatment scores} - \textit{Mean of baseline scores}}{\textit{Standard deviation of baseline data}}$$

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Set 3 baseline scores (B1-B3) demonstrated zero variance, with which ESs cannot be calculated. A pooled standard deviation of Set 1 and Set 2 baseline data was therefore used as the denominator for Set 3 ES calculations (cf. Beeson & Robey, 2006). Following Maas and Farinella (2012), a significant improvement was operationally defined as an ES greater than 1.0. This implied that the magnitude of the change was greater than the standard deviation (Maas & Farinella, 2012).

11. Post-hoc data analysis

WWA analyses provided information on the effect of the SML treatment on speech production. However, following the WWA analyses, the researcher was interested in the possible effect of the SML on the nature of errors. The nature of errors may indicate the level of breakdown (Van der Merwe, 1997; 2009) during speech production. Specifically, the nature of errors may reflect the phonological versus motoric nature of the breakdown. A post-hoc analysis on error types was therefore performed as an initial exploration of the way in which improvement may affect the nature of errors over the course of the study.

For all three sets of sounds, non- and real-word stimuli which were scored as "incorrect" during the WWA analyses, were further judged to determine the nature of errors on a sound (segmental) level. Narrow phonetic analysis was done. The nature of errors that occurred on each sound in a nonword or real word was judged according to three error categories: phonetic-motoric errors, phonological errors and ambiguous errors. *Phonetic-motoric errors* comprised consonant distortions (inaccurate productions of a specific sound) due to disruptions in temporal or spatial specifications and distorted coarticulation between sounds. Voice onset time (VOT) errors, which include voicing of voiceless sounds or devoicing of voiced sounds, as

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perceived perceptually, were also noted as phonetic-motoric errors. *Phonological errors* included additions, omissions, and trans-positioning of well-produced phonemes. Substitutions and distorted substitutions of consonants, as well as all vowel errors, were classified as *ambiguous errors* as they could not adequately be attributed to either a phonetic-motoric or a phonological breakdown. Although substitutions can be viewed as linguistic errors, it has been argued in the field of apraxia that an apparent substitution may also originate from a motor planning and/or programming problem (McNeil et al., 1997; 2009). Distorted substitutions are considered phonetic-motoric errors (McNeil et al., 1997; 2009), but it may also be possible that a distorted substitution may be the result of the incorrect selection of a phoneme at the phonological level, which is distorted at the phonetic-motoric level. Due to the Participant's young age, it was not always possible to confidently determine whether an error was a pure substitution or a distorted substitution. For the foregoing reasons, both substitutions and distorted substitutions were categorised as ambiguous in this study. Following Van der Merwe (2011), vowels errors were classified as ambiguous as it was nearly impossible to determine perceptually if a vowel was substituted or distorted.

A fourth error category, *No Score* (NS), was specified for isolated incidences of productions that could not be scored due to disrupting behaviour of the Participant or productions in which an attempt was made, but individual sounds were distorted to such an extent that they were not identifiable for perceptual analysis scoring. Probe items scored as NS were excluded from the error analysis. See Table 5 for examples of the scoring rubric that was applied to all probe stimuli.

Raw scores for error types were then processed and the percentage errors per category for each non- or real-word set as a proportion of the total errors per

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non- or real-word set were plotted for the three sets of non- and real-words (see Figures 4 to 6 in Chapter 3). The graphs plotted served to determine, by visual analysis, if there was a change in the nature of errors across the entire study duration. A great deal of fluctuation in the percentages of errors was, however, present from one probe session to the next. The average number of errors per error category for each non- or real-word set as a proportion of the total errors per set during baseline (B1-B3) and follow-up (F1-F2 for Set 1 or B13-B14 for Sets 2 and 3) phases was therefore calculated (see Table 7 in Chapter 3). These averages allowed a summative, but more meaningful interpretation of the change in the nature of errors from pre- to post-treatment.

Table 6. Scoring rubric as applied during the perceptual analysis of the nature of errors, with examples of errors from each of the error categories.

Error category	Description	Example
Phonological errors.	C or V omission C or V addition C or V trans-positioning	/sæli/ → [tæi_] /bini/ → [bindi]* /bɔdu/ → [dɔbu]*
Phonetic-motoric errors.	C distortion VOT errors	/sænɛ/ → distorted [s] /nitɛ/ → [t] with inappropriate voicing
Ambiguous errors.	All V errors C substitutions Distorted substitutions of C	/mæni/ → [mɛni] V substitution or distortion (Here, it was difficult to perceptually determine whether a substitution, a distortion or both errors had occurred.) /fænu/ → [pænu] /vɛnɔ/ → [v] displayed elements of bilabial plosive release
No Score (NS).	Disruptive behaviour Production attempted, but individual sounds not identifiable	Refusing to say a word /lulu/ → [u] with distortion of entire utterance

Notes: C = consonant, V = vowel, VOT = voice onset time. * Examples given are fictitious errors.

12. Validity and Reliability

Validity refers to the "extent to which the data represent the phenomenon being assessed," while reliability refers to "the stability of the methods used to obtain the data" (Barlow et al., 2009, p. 129). Both the WWA analysis and the post-hoc nature of error analysis focus on the effect of treatment on speech production, and were considered valid measurements thereof. The primary research did not perform the analyses. Twenty per cent (20%) of probe recordings were re-analysed to determine the reliability of the perceptual analyses of WWA and nature of errors. Point-to-point agreement between the result of the initial analysis and the re-analysis for each probe item was determined. For WWA, reliability was 87%. For the post-hoc analysis, reliability for type of error detected in incorrect words was 92% (for phonological errors), 80% (for phonetic-motoric errors) and 78% (for ambiguous errors). These high agreement levels confirm the stability of the data collection methods.

13. Summary of Chapter 2

This chapter has provided an explanation of the methods followed in this study, which investigated the effects of the SML approach (Van der Merwe, 1985; 2011) on the speech production of a child with CAS. The aim and sub-aims of the research were specified at the onset of the chapter. Thereafter, the selected Participant, the ethical aspects considered in the study, and the design implemented were described. A discussion of the experimental stimuli, the procedures followed and the outcomes measures was provided. Finally, the processing and analysis of the data were described. The results of the current study will be presented in the next chapter.

CHAPTER 3: RESULTS AND DISCUSSION OF RESULTS

1. Introduction to Chapter 3

In this chapter the results of the WWA analysis are presented according to the sub-aims specified in section 2 of Chapter 2. The results of the post-hoc error analysis are also presented in this chapter. Thereafter, the results of the current study are discussed.

2. Results: Whole word accuracy

2.1. Whole word accuracy: Treated sounds (Sub-aim 1)
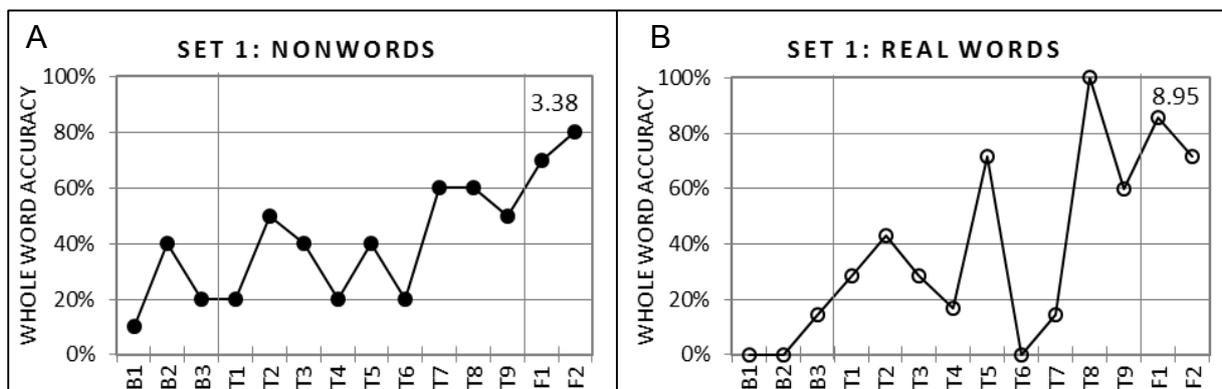
Figure 1. Whole word accuracy (% correct) for Set 1 nonwords (A) and real words (B) containing treated age-appropriate sounds. Effect sizes (ES) are also indicated. Note: B = Baseline, T = Treatment, F = Follow-up.

Figure 1 displays the results of the WWA analysis for Set 1 non- and real-word stimuli. The Participant demonstrated a significant improvement in WWA for Set 1 nonwords (ES = 3.38) and real words (ES = 8.95) containing the *treated* sounds. Considerable fluctuation in his performance was, however, evident across the duration of the study. Accuracy scores for Set 1 nonwords (Figure 1A) ranged

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between 10% and 40% at baseline phase and increased to 70% and 80% at follow-up. Accuracy scores of real words (Figure 1B) ranged between 0% to 14.3% at baseline, with improvement to 85.7% and 71.4% at follow-up. ES calculations indicated a greater degree of improvement in WWA for real words than for nonwords, though visual inspection revealed larger variation in performance from probe to probe for real words than for nonwords.

2.2. Whole word accuracy: Untreated age-appropriate consonants (Sub-aim 2)
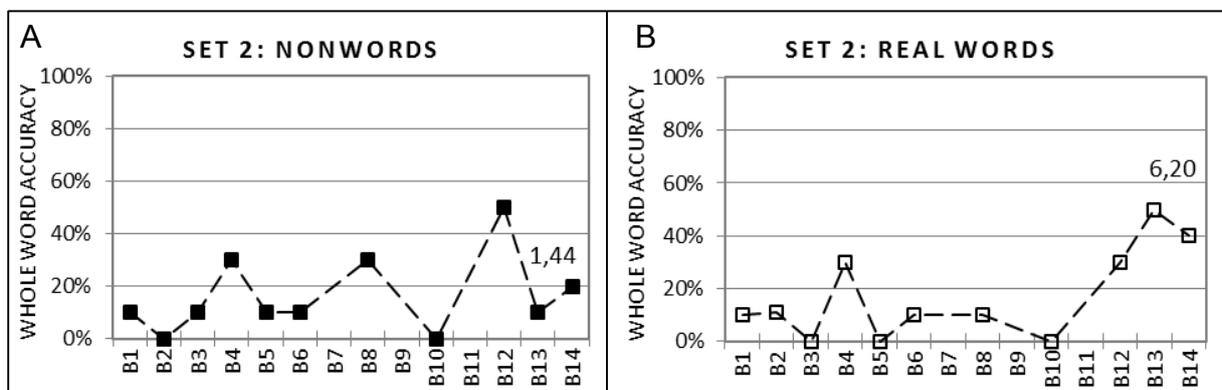
Figure 2. Whole word accuracy (% correct) for Set 2 nonwords (A) and real words (B) containing an untreated age-appropriate consonant. Effect sizes (ES) are also indicated. Note: B = Baseline.

The results of the WWA analysis for Set 2 non- and real-word stimuli are presented in Figure 2. Set 2 non- and real-words containing an *untreated* age-appropriate consonant evidenced slightly higher scores in WWA towards the end of the study. Fluctuation in performance was also noted across the data collection period. The initial three baseline scores (B1-B3) varied between 0% and 11.1% correct for both nonwords (Figure 2A) and real words (Figure 2B), followed by a score of 30% for the fourth baseline probe (B4). Nonword scores fluctuated between 0% and 30% correct from the fifth baseline probe (B5) to the tenth (B10), while real word scores remained

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either 0% or 10% correct. At the twelfth baseline probe (B12), the score for nonwords increased to 50% correct, but decreased to 10% and 20% respectively for the final two baseline probes (B13-B14). For real words, the Participant's score increased to 30% correct at B12 and 50% at B13, but decreased to 40% correct at B14. ESs indicated that higher scores were significant (nonwords ES = 1.44, real words ES = 6.20). However, Set 2 ESs remained lower than those of Set 1.

2.3. Whole word accuracy: Untreated age-inappropriate sounds (Sub-aim 3)
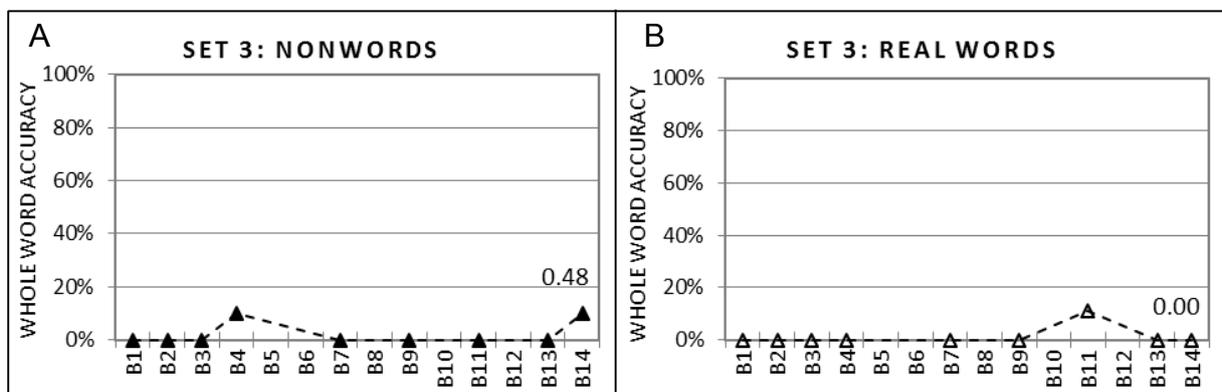
Figure 3. Whole word accuracy (% correct) for Set 3 nonwords (A) and real words (B) containing an untreated age-inappropriate consonant. Effect sizes (ES) are also indicated. Note: B = Baseline.

WWA results for Set 3 non- and real-word stimuli are depicted in Figure 3. No significant change in WWA was observed for Set 3 nonwords (ES = 0.48) and real words (ES = 0.00) containing an *untreated age-inappropriate* consonant. Stable baseline measures of 0% correct were demonstrated for both nonwords (Figure 3A) and real words (Figure 3B) between B1 and B12, with an isolated score of 10% and 11.1% correct for nonwords (at B4) and real words (at B11) respectively. During the final two baseline probes, nonword accuracy increased minimally to 10% correct (B14), while real word accuracy returned to 0% correct.

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3. Post-hoc results: Nature of errors

Figures 4 to 6 display the percentage errors per category for each non- or real-word set as a proportion of the total errors for the non- or real-word stimuli of Set 1 (treated age-appropriate sounds), Set 2 (untreated age-appropriate consonants) and Set 3 (untreated age-inappropriate consonants). The average number of errors per error category per set as a proportion of the total errors for each non- or real-word set during baseline (B1-B3) and follow-up (F1-F2 or B13-B14) phases are tabulated in Table 7. Data from Figures 4 to 6, and Table 7 provided information for exploring the way in which improvement affected the nature of errors over the course of the study.
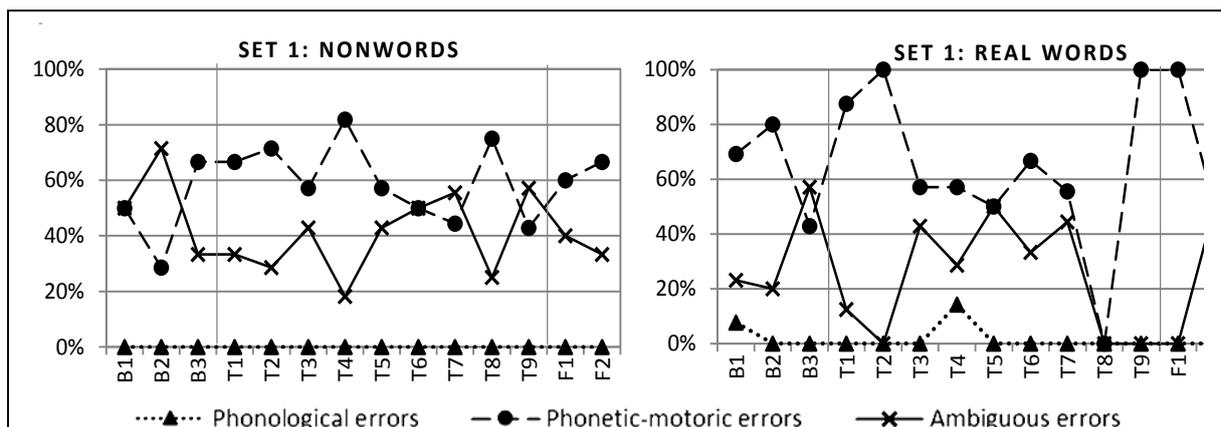
Figure 4. Number of errors per category as a proportion of the total errors for Set 1 nonwords (A) and real words (B) containing treated sounds only.
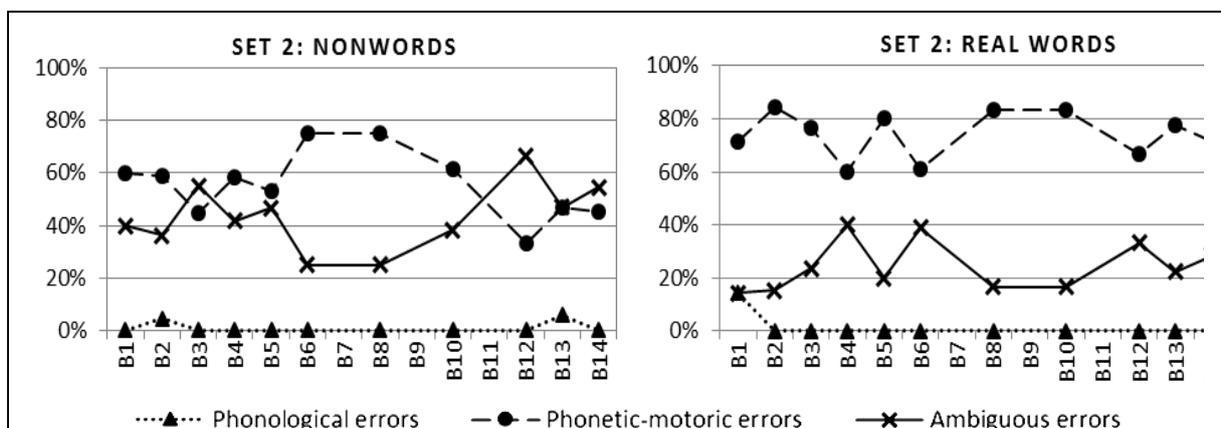
Figure 5. Number of errors per category as a proportion of the total errors for Set 2 nonwords (A) and real words (B) containing an untreated age-appropriate consonant.

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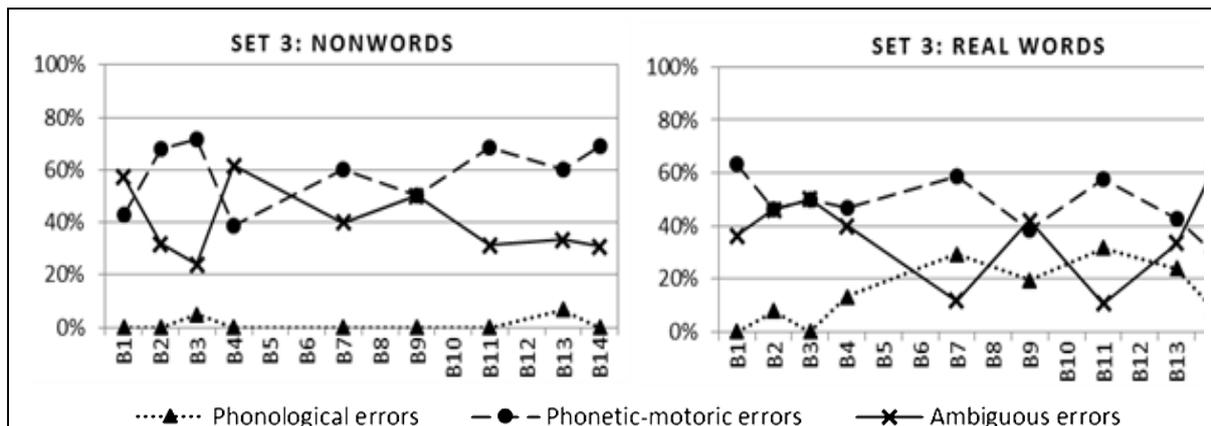
Figure 6. Number of errors per category as a proportion of the total errors for Set 3 nonwords (A) and real words (B) containing an untreated age-inappropriate consonant.

Table 7. The average number of errors per category, as a percentage of the total errors for baseline (B1-B3) and follow-up (F1-F2) phases for Set 1, and B1-B3 and B13-B14 for Set 2 and 3.

	NONWORDS					
	Set 1		Set 2		Set 3	
	B1-B3	**F1-F2**	**B1-B3**	**B13-B14**	**B1-B3**	**B13-B14**
Phonetic-Motoric	50.0%	62.5%*	54.4%*	46.4%	60.9%*	64.3%*
Ambiguous	50.0%	37.5%	43.9%	50.0%*	37.5%	32.1%
Phonological	0.0%	0.0%	1.8%	3.6%	1.6%	3.6%

	REAL WORDS					
	Set 1		Set 2		Set 3	
	B1-B3	**F1-F2**	**B1-B3**	**B13-B14**	**B1-B3**	**B13-B14**
Phonetic-Motoric	62.2%*	66.7%*	77.3%*	75.0%*	52.6%*	36.4%
Ambiguous	35.1%	33.3%	18.2%	25.0%	44.7%	47.7%*
Phonological	2.7%	0.0%	4.5%	0.0%	2.6%	15.9%

* Indicates the **highest** average errors for each phase.

Visual inspection of the post-hoc data revealed a predominance of phonetic-motoric and ambiguous errors for both nonwords and real words across all sets and phases (see Figures 4 to 6). Fluctuation of phonetic-motoric errors and ambiguous errors from one probe session to the next was, however, evident. At *baseline phase* (B1-B3), phonetic-motoric errors and ambiguous errors were, on average, of equal proportion (50%) for Set 1 nonwords only (Figure 4A, Table 7). More phonetic-

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motoric than ambiguous errors were observed at baseline for Set 1 real words (Figure 4B, Table 7), Set 2 and 3 nonwords and Set 2 and 3 real words (Figures 5 and 6, Table 7). Throughout the *treatment phase* of Set 1 (B4-B12 for Sets 2 and 3), phonetic-motoric errors predominated for all word types of all sets (Figures 4 to 6). More phonetic-motoric than ambiguous errors were also noted in four out of six incidences at *follow-up* (Set 1 nonwords and real words [F1-F2], Set 2 real words, and Set 3 nonwords [B13-B14]; see Figures 4 to 6 and Table 7). Only isolated incidences of phonological errors were recorded across the duration of the study, with most incidences noted for Set 3 real words (Figure 6B).

With regard to the question of how errors may represent the effect of the SML treatment on nature of errors, three notable changes in the average number of errors per error category, following the treatment period, were observed (see Table 7). The proportion of phonetic-motoric errors for Set 1 nonwords increased from an average of 50% to 62.5%. For Set 3 real words, the proportion of phonetic-motoric errors decreased from an average of 52.6% to 36.4%, while phonological errors increased from an average of 2.6% to 15.9%.

The fourth error category, *No Score* (NS), was used for isolated instances of productions that could not be scored. Probe items scored as NS were not included in the processing of the error analysis (that is, in Figures 4 to 6 or Table 7), but are briefly described here. A total of 23 NSs were recorded across the study duration; 18 were recorded during baseline, four during the treatment phase and one during follow-up. NSs were most often recorded for Set 3 real words containing untreated age-inappropriate sounds, specifically the words 'valley', 'Lulu', 'Sally', and 'belly'. The number of NS scores for Set 3 real words decreased across B1-B3 (n = 9), B4-B12 (n = 4) and B13-B14 (n = 1) probes.

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4. Discussion of results

In summary, the results show that the Participant demonstrated a significant improvement in whole word accuracy of *untreated* non- and real words containing *treated* sounds (Set 1). Less change was observed in untreated stimuli containing *untreated* age-appropriate consonants (Set 2) and no change was seen for untreated stimuli containing an *untreated age-inappropriate* consonants (Set 3). Considerable fluctuation in whole word accuracy was observed over time, particularly for Set 1 stimuli. The post-hoc analysis revealed a predominance of phonetic-motoric errors throughout the study. Only Set 3 real words showed a marked change in the number of phonological errors.

In this section, the results of the whole word accuracy scores and the implications thereof are discussed according to the sub-aims of the current study. Possible explanations for the variability in performance are provided. Thereafter, the nature of errors, and the change in these errors across time, is discussed.

4.1. Treatment effects (Sub-aim 1)

Untreated non- and real-word stimuli containing Set 1 treated sounds showed an improvement in whole word accuracy following the 18 treatment sessions. Effect sizes were greater than 1.0, indicating that improvement in accuracy was significant. Improved nonword accuracy reflects *response generalisation* of treatment effects to untreated nonword exemplars of treatment stimuli. As nonwords were utilized as treatment stimuli, the generalisation from nonwords to real words indicates *stimulus generalisation* (Ballard, 2001; Olswang & Bain, 1994). These findings suggest that the SML approach (Van der Merwe, 1985; 2011) was effective in improving speech production for this Participant. However, it is important to acknowledge that the

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results for Set 1 real words should be interpreted with some caution. The visually increasing trend in WWA of Set 1 real words during the baseline phase and first two treatment probes (Figure 1B) makes it uncertain whether the SML treatment alone was responsible for the increase in accuracy of these stimuli. It is possible that maturation may have played a role, though this is unlikely given that these probes were collected across a relatively short period of time. The real word stimuli were common words, which the Participant may have been exposed to in his home environment. These words also contained sounds that the Participant produced with the greatest ease of production (rated "1"). One may therefore expect some correct productions during probes. The decrease in WWA at T3 and T4, the subsequent rise across the treatment period, and the large ES for real words at follow-up provide some support for the interpretation that improvement was due to treatment. Additionally, Set 1 improvement exceeded that of the untreated Sets 2 and 3, further supporting the impression that improvement was likely due to treatment.

The results appear to suggest that the components of the SML approach implemented in this study may have contributed to the generalisation of treatment effects to untreated exemplars of treatment stimuli and to real words containing treated sounds. The premise of the SML approach is to facilitate speech motor learning and improve speech motor planning ability. Improved motor planning skills, as depicted in the four level framework (Van der Merwe, 1997; 2009), are specifically targeted through the SML treatment methods, and are proposed to underlie gains in speech production ability. In this approach, movement parameters for individual target sounds are taught in nonword treatment stimuli. The ability to plan consecutive and concurrent movements, as well as successfully adapt movement parameters to different phonetic environments, is developed (Van der Merwe, 2011). Different

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treatment strategies employed in the SML may enhance motor learning. Blocked practise of nonwords, with KP and KR augmented feedback, may facilitate the Participant's initial acquisition of these skills. Also, imposing a response delay for nonwords enables a child with CAS to do mental practice of the movements for sounds and this may promote internal feedback control. The treatment targets which are implemented in the SML approach, namely easier sounds in nonwords and a systematic variation of the sound environment to facilitate adaptation of core motor plans of sounds, may also contribute to improved speech motor planning skills. The use of nonwords in the SML treatment allows multiple combinations of sounds, facilitating plasticity in the core motor plans of target sounds and providing opportunity to rehearse coarticulation of different sound combinations (Van der Merwe, 2011). The randomised variable practice afforded by nonwords may promote generalisation of treatment gains to untreated nonword exemplars and real words.

Recent research, such as that of Gierut and colleagues (Gierut, Morrisette, & Ziemer, 2010; Gierut & Morrisette, 2010), supports the generalisation potential of nonword treatment stimuli. The generalisation of treatment effects to untreated stimuli and to real words in the present study provides further support for the use of nonwords in clinical practice. Implementation of nonwords as a treatment strategy is also supported by other studies in CAS treatment research, which report generalisation with ESs similar to those in the current study. For example, Thomas et al. (2014) report that two of their participants demonstrated ES of 3.918 and 2.391 respectively, for generalisation to untreated nonwords which were similar to treated nonwords. Large ES were also noted for generalisation to untreated real words, though the effects differed across participants and across the number of syllables in real words (Thomas et al., 2014). Ballard and her colleagues also report positive

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generalisation of treatment gains to untreated nonword exemplars, but mixed generalisation to real words (Ballard et al., 2010). Despite the large ES obtained for Set 1 real words in the current study, visual analysis of Figure 1B revealed a descending trend in WWA at F2. Given the variability observed during the treatment period, it is not certain whether this trend would have continued or whether the improved accuracy in real words would have been maintained after F2. Follow-up probes across a longer period of time would have provided more information regarding the long-term maintenance of skills which had generalised to real words.

Though nonwords were used as treatment stimuli in the present study, real words achieved better generalisation scores overall than nonword exemplars. The motivational value of real words and the fact that the Participant could have heard these words in his environment may promote learning to some extent. It is also possible that, while the *absence* of meaning (linguistic content) in nonwords aids the *initial improvement* in the underlying ability to plan movements, the *presence* of meaning in words may facilitate *generalisation* of these skills to a greater extent in real words than in nonwords. Van der Merwe (2011) also observed greater generalisation to untreated real words than to nonwords in her application of the SML approach to the treatment of an adult with AOS. She suggests that real words (in adults) may involve more automated production and therefore respond more readily to the improved planning skills achieved through the SML treatment.

4.2. Generalisation to untreated, age-appropriate consonants (Sub-aim 2)

Slightly higher WWA scores were seen for Set 2 untreated consonants towards the end of the study. Set 2 non- and real-word WWA scores fluctuated between 0% and 30% correct from B1 to B10 and increased slightly only at B12. These scores did not

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exceed 50% correct at any point in the study. Though these scores suggest a loss of experimental control, alternative clarifications may be proposed.

Gradual improvement in motor planning skills occurred and could have generalised to other age-appropriate consonants, which the Participant found fairly easy to produce (rated "1" or "2"). Two of the Set 2 consonants (/d, p/) were voiced or voiceless cognates of Set 1 consonants (/t, b/). The Participant may have learnt the *spatial* parameters for place of articulation during Set 1 treatment. He also learnt the *voicing contrast*, given that Set 1 included both a voiced and voiceless consonant. It is likely that he was able to apply these skills to Set 2 consonants and this may be the reason why the Set 2 cognates improved after a period of treatment on Set 1 consonants. Furthermore, following the methods of the SML approach (Van der Merwe, 2011), the stimuli of Set 2 each contained treated and untreated consonants. Coarticulation likely becomes easier as the Participant's ability to correctly specify, adapt and centrally monitor movement parameters for consecutive sounds, improves. In other words, improved production of Set 1 sounds seems to ease coarticulation of the sounds in Set 2 stimuli, resulting in correct productions of some nonwords and real words, albeit inconsistently. Application of the SML to the treatment of an adult (Van der Merwe, 2011) also resulted in generalisation to some slightly difficult to moderately difficult sounds before treatment on these sounds commenced. The explanation offered for this was that the Participant "gained experience in motor planning and could apply his improved ability to the production of other untreated sounds… that he found relatively easy to produce" (Van der Merwe, 2011, p. 1200). Although the treatment period in the current study was restricted to 9 weeks, it may also be possible that some development took place and

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that the higher Set 2 scores were not only due to treatment of other age-appropriate sounds of Set 1.

4.3. Generalisation to untreated, age-inappropriate consonants (Sub-aim 3)

Virtually no change in WWA was observed for Set 3 non- and real-words containing untreated, age-inappropriate consonants. In terms of the age of their acquisition, the consonants of Sets 3 fall within the middle 8 (/v/) and late 8 (/l, s/) stages of Shriberg's (1993) profile of acquisition, and are typically mastered after four years of age (Bernthal et al., 2009, pp. 91-92, Table 3.3). The Participant in this study was only 33 months of age. From the perspective of the four level framework (Van der Merwe, 1997; 2009), it would appear that he had not acquired the core motor plans for these untreated sounds and was not able to plan movement parameters for them. Coarticulation between the sounds within Set 3 non- and real-words may have remained difficult due to the high motor complexity of these sounds.

4.4. Variability in performance over time

Visual inspection of the data revealed considerable fluctuation in the Participant's performance over time, particularly for Set 1 stimuli which improved in accuracy across time. WWA scores for Set 1 nonwords ranged between 10% and 80% correct across the duration of the study, while real words ranged between 0% and 85.7% correct (see Figure 1). Sets 2 and 3, which evidenced little or no improvement, were more consistently incorrect (see Figures 2 and 3). A number of other CAS treatment studies also report fluctuation in performance across time for all or some of their participants (for example: Edeal & Gildersleeve-Neumann, 2011; Maas et al., 2012; Preston et al., 2013; Strand et al., 2006).

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Variability (or inconsistency) in performance is expected since it is characteristic of both typical speech development in young children (Holm, Crosbie, & Dodd, 2007) and CAS (ASHA, 2007; Marquardt et al., 2004). However, variability is also characteristic of the initial stages of motor learning during the acquisition of motor skills in general, with performance becoming more consistent and more stable towards the final stages (Magill & Anderson, 2014). It would seem that the Participant's ability to consistently plan, sequence and adapt movement goals of the core motor plans for Set 1 sounds had not yet progressed into the final stages of motor learning during the 18 treatment sessions. Though the Participant may have acquired these motor planning skills, the consolidation and stabilisation thereof may have required more time. Edeal and Gildersleeve-Neumann (2011) provide a similar explanation for the instability observed in the performance of their two participants.

Stability of performance may be influenced by external or internal factors (Magill & Anderson, 2014), for example environmental conditions, emotional state, and fatigue. Informal observations during the treatment and probe sessions suggest that such factors may have influenced the Participant's performance across probe days and may have been responsible, in part, for the variability observed. The Participant was 33 months old at the time of the study and, as expected from young children, his motivational and attention capacity fluctuated often. On some days he cooperated well, while on other days his cooperation was poorer. This had a marked influence on his performance (compare, for example, T6 [poor] and T8 [better] probe days). Several authors (Dale & Hayden, 2013; Edeal & Gildersleeve-Neumann, 2011; Maas et al., 2012; Maas & Farinella, 2012; Preston et al., 2013; Strand et al., 2006) cite individual participant characteristics, such as motivation, cooperation, emotional state, age and CAS severity, as influencing participants' response to

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treatment, as well as the stability of their performance on treated or untreated items over time.

4.3. *Post-hoc analysis: Nature of errors*

The nature of errors which occurred across time was analysed in addition to WWA, to explore the way in which improvement affected the nature of errors over the course of the study. The nature of errors may indicate the level of breakdown (Van der Merwe, 1997; 2009) during speech production. Specifically, the nature of errors may reflect the phonological versus motoric nature of the breakdown. To this end, three error categories were specified: phonetic-motoric, phonological and ambiguous errors.

In this study, the Participant made more phonetic-motoric and ambiguous errors than phonological errors (see Figures 4 to 6 and Table 7). Common *phonetic-motoric* errors demonstrated by the Participant included voice onset time (VOT) errors (for example: /d/ produced as [t]), and consonant distortions arising from inappropriate or mistimed velopharyngeal movement (for example: /n/ produced as a distorted [d]). Within the four-level framework of speech motor planning and programming (Van der Merwe, 1997; 2009), these errors can be attributed to a difficulty in motor planning of spatiotemporal parameters of movements, when muscle tone and execution of movement are intact. The Participant's inability to plan and control interarticulatory synchronisation, to adapt spatiotemporal movement parameters in core motor plans to the phonetic context and to keep these adaptations within the limits of equivalence probably gave rise to distortions and VOT errors (Van der Merwe, 1997; 2009).

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The *ambiguous* errors consisted mostly of vowel errors (for example: /æ/ produced as [ɛ]) and distorted substitutions (for example: /v/ produced as [v] with elements of bilabial plosive release). Either a phonetic-motoric or a phonological breakdown may be possible causes for errors scored as ambiguous. If broad phonetic analysis had been done, many distorted substitutions and vowel errors would likely have been classified as substitutions (for example: the [v] with elements of bilabial plosive release would have been scored as a [b]). A consonant or vowel substitution may result from the selection of an incorrect phoneme during phonological planning, but it may also be due to a distortion of the temporal and spatial parameters of movement for the intended sound during motor planning and/or programming (McNeil et al., 1997; 2009; Van der Merwe, 1997; 2009). For example, plosion, instead of friction, may have been specified at the motor planning level. It may also be possible that a distorted substitution may be the result of the incorrect selection of a phoneme at the phonological level, which is distorted at the phonetic-motoric level. With regard to vowel errors, distortions and substitutions of vowels are often perceptually indistinguishable. Determining the exact nature of vowel errors is, therefore, problematic. Ambiguous errors could, therefore, not be attributed confidently to either phonetic-motoric or phonological breakdown. Consequently, limited information could be inferred from this error category. However, the high proportion of phonetic-motoric errors does support the notion that the underlying deficit in CAS is at the level of motor planning and/or programming (ASHA, 2007; Hall et al., 2007) o**r** motor planning of speech (Van der Merwe, 1997; 2009).

With regard to *phonological errors*, Sets 1 and 2 stimuli showed almost no phonological errors (see Figures 4 and 5). Set 3 real words were the only probe stimuli that evidenced a change in phonological errors over time; a slight increase

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was observed over the period from B4 to B14 (see Figure 6B). After looking more closely at the data, it was noted that the majority of the Participant's phonological errors comprised omissions of the /l/ sound in the medial position of Set 3 real words, specifically 'belly', 'Lulu', 'Nelly', 'Sally', and 'valley'. At the time of the study, the /l/ sound was age-inappropriate and was consistently produced incorrectly (rated "4") during the pre-treatment sound production assessment. During B1-B3, most words containing the /l/ sound were distorted to such an extent that individual sounds could not be distinguished. These words were scored NS and excluded from the error analysis. As mentioned in the results, NSs were most often recorded for Set 3 real words, specifically the words 'valley', 'Lulu', 'Sally', and 'belly'. After the commencement of treatment on Set 1 sounds (B4 for Set 3 real words), less NS scores were noted (B1-B3 = 9, B4-B12 = 4 and B13-B14 = 1) and individual sounds, though still inaccurately produced, could be identified. As a result, errors made during the period from B4 to B14 could actually be scored. It is during this time that an increase in the number of phonological errors (primarily, omission of medial /l/) was observed for Set 3 real words. The increase in phonological errors appeared to coincide with the decrease in NS ratings. Possible explanations for this occurrence, though speculative, are briefly provided here.

The high number of NSs during B1-B3 for Set 3 real words suggests that the Participant was not able to produce the /l/ at all, nor attempt to coarticulate the different sounds in the words. The fact that different sounds could be identified later (as reflected in the decrease in NSs) and that the /l/ sound was omitted suggests that the Participant's overall speech motor planning ability improved. It is possible that his ability to separate the /l/ sound from the other sounds improved to such an extent that he was able to plan and produce the other sounds, while omitting the /l/.

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From a phonological perspective, it may be that the /l/ sound was not yet established in the Participant's phonemic repertoire. His omission of the medial /l/ sound may be a developmental phonological process that he applied to compensate for the absence of this sound in his phonemic repertoire. Deletion of medial consonants has been reported as an atypical phonological process which may persist beyond four years of age (Hall et al., 2007; Strand & Skinder, 1999).

Alternatively, omissions, which reduce the number of phonemes in an utterance, may be a strategy that some children with CAS use to lessen the complexity demands on the motor planning system (Yorkston, Beukelman, Strand, & Bell, 1999). Omission errors are reportedly prominent in younger children with CAS (Hall et al., 2007; Rosenbek & Wertz, 1972; Shriberg et al., 1997a). As the children become older, omission errors tend to decrease, while substitutions and distortions become more prevalent (Hall et al., 2007). Given the Participant's young age (33 months old), it is reasonable to expect that he would still make omission errors, as observed, in addition to distortions and substitutions. It is proposed that the distortions and substitutions occurred on age-appropriate sounds (Set 1 and 2), and that the Participant applied the omission strategy to the /l/ sound, because it was a motorically more complex sound, usually acquired after four years of age. Of the Set 3 probe stimuli, 55% of real words contained a medial /l/, while only 10% of nonwords did. This distribution was unintentional and was determined by the number of meaningful CVCV words which could be formed given the available sounds. It could, however, clarify why Set 3 nonwords did not evidence as many phonological errors as real words did.

5. Summarised discussion

In summation, WWA scores improved for untreated stimuli containing treated sounds, while stimuli containing untreated sounds showed less or no significant change. These results suggest that the SML approach (Van der Merwe, 1985; 2011) was effective in significantly improving the production of treated sounds and this improvement generalised to untreated nonword exemplars and real words. Improved motor planning of treated sounds and better coarticulation of consecutive sounds in non- and real-word stimuli, achieved through the SML treatment, are proposed to underlie the observed improvements in speech production. Response and stimulus generalisation of treatment gains to untreated stimuli provides support for the target selection and methods of the SML approach, as implemented in this study. The Participant's improvement was brought about by the implementation of nonwords containing a group of easy consonants and vowels as treatment stimuli. Intensive repetition during blocked practice of nonwords and the use of integral stimulation, augmented feedback and mental practice effected an improvement in motor planning ability. Also, randomised variable practice achieved through the inclusion of more than one sound, and the systematic variation of phonetic environments, facilitated learning of the adaptation of motor plans and coarticulation of sounds. The results support the notion that the SML approach targets and improves the underlying motor planning deficit in CAS.

The post-hoc error type analysis revealed that phonetic-motoric and ambiguous errors predominated throughout the study. This finding reinforces the theoretical notion that the underlying nature of CAS is motor-based, and specifically that the core deficit is "in planning and/or programming spatiotemporal parameters of movement sequences" (ASHA, 2007, p. 4). The decrease in the number of Set 3

words that were distorted to such an extent that individual sounds could not be distinguished (*NS error score)*, with a coinciding increase in phonological errors (omission of medial /l/), points to an improvement in overall motor planning ability of single and coarticulated sounds following treatment on Set 1 sounds.

6. Summary of Chapter 3

In this chapter, the results were presented according to the different sub-aims of the study. The results of a post-hoc analysis were also described. After the presentation of the results, these were discussed and possible explanations for the different results were provided.

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CHAPTER 4: CONCLUSIONS

1. Introduction to Chapter 4

In this final chapter, the conclusions and implications of the study are presented, together with a brief discussion of the limitations of the study and recommendations for future research.

2. Conclusions

The present study has investigated the application of the SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) in the treatment of CAS. As an introduction to this study, an overview of the history of the disorder was presented, followed by a review and evaluation of the current state-of-the art of CAS treatment research. The need for a treatment approach, in which both the treatment targets and treatment methods and strategies are informed and guided by a comprehensive theoretical model of speech sensorimotor control, was highlighted. The SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) was proposed as such a treatment approach and the theoretical model which informs the approach, together with the rationale for treatment stimuli and strategies as derived from this model, were explained. The study applied the SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) to the treatment of a child with CAS in a single-case experimental study, with multiple baselines and multiple probes across behaviours. The effect of the treatment on the child's speech production was evaluated in terms of whole word accuracy. A post-hoc analysis of the nature of errors made across time was also performed. The following conclusions were drawn from the results:

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- The Participant's production of untreated nonword exemplars containing treated sounds improved significantly, demonstrating acquisition and response generalisation.

- Improvement also generalised to untreated real words, suggesting stimulus generalisation of newly learned motor skills.

- The improvement in speech production was maintained two weeks post treatment.

- More accurate production of stimuli containing treated sounds was attributed to improved motor planning of treated sounds and better coarticulation of these sounds in non- and real-word stimuli.

- The fact that stimuli containing other untreated age-appropriate consonants (Set 2) also improved slightly suggests that improved motor planning and coarticulatory ability generalised to untreated age-appropriate sounds as they appeared together with already treated age-appropriate sounds in non- and real-words

- It was proposed that the aspects of the SML approach implemented in this study effected a significantly positive change in the speech production of a 33-month-old child with CAS, across a treatment period of nine weeks. No harm was done as the child showed improvement across the duration of the treatment. This study provides Level IIb, proof of concept evidence in support of the application of the SML approach in the treatment of CAS.

- The components of the SML approach that were implemented in this study, namely: the use of CVCV nonwords, the initial use of sounds with the greatest ease of production, systematic increase in the amount of variation in phonetic environments (increasingly more variable practice), multiple speech sound

targets (random practice), fading knowledge of response feedback, repeated drill work (blocked practice), and mental practice, was sufficient to bring about change in the speech production of this participant.

- The post-hoc error analysis revealed a predominance of phonetic-motoric and ambiguous errors across time, consistent with a disorder at the level of planning and/or programming of speech.

- In addition, the decrease in the number NSs for Set 3 real words, with a coinciding increase in phonological errors (omission of medial /l/) indicated an improvement in the ability to coarticulate sounds.

3. Implications of the study

The findings of the present study have several implications for clinical practice and research. These implications are:

- The treatment of CAS should be guided by a comprehensive theoretical model, which explains the underlying cause of the symptoms of CAS, and provides guidelines for both the selection of treatment stimuli and the methods implemented. The four level framework of speech sensorimotor control (Van der Merwe, 1997; 2009) is advocated here as one such model.

- The SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) holds promise as an effective approach for the treatment of CAS, in both clinical and research contexts.

- The use of nonwords as treatment stimuli, particularly in the treatment of CAS, is recommended in light of the growing evidence suggesting that nonwords result in better generalisation and maintenance of treatment gains (Ballard et al., 2010; Gierut & Morrisette, 2010; Thomas et al., 2014).

- In their recent systematic review of the AOS treatment literature, Ballard et al. (2015) raise the concern that it is not clear which aspects of the SML treatment bring about changes in speech production. However, the target selection and methods of the SML approach, as a whole or "package", are proposed to bring about an improvement in the speech production of individuals with apraxia of speech (Van der Merwe, 2011). While attempting to isolate one or a few aspects of the SML approach as essential may be difficult or, in some aspects, impossible (such as the use of nonwords, which is integral to this approach), consideration may be given to an attempt to optimise the treatment "package" of the SML approach over time.

4. Limitations and recommendations for future research

While the present study provides Level IIb evidence in support for the application of the SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) in the treatment of CAS, a number of limitations can be identified. These limitations should be considered in the interpretation of the findings reported. Future studies may address some of these limitations. The limitations and recommendations for future research include:

- Only one child with CAS participated in this study. Children with CAS are a heterogeneous population and generalisation of the study findings to other children with CAS should therefore be made with caution. Individual participant characteristics, age, severity of CAS and presence of comorbid disorders all influence participants' responses to treatment in a variety of ways. Future research on the SML approach (Van der Merwe, 1985; 2011) should include replication across a larger number of participants with CAS,

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and should include a wider range of age groups. Participant characteristics that may affect responsiveness to SML treatment should be identified.

- The lack of a stable baseline for Set 1 stimuli, particularly Set 1 real words, also suggests that caution should be exercised in interpreting the current study's data.

- The current investigation was limited to a short treatment period of 9 weeks. Variability in the Participant's performance across probes suggested that treatment effects had not stabilised within this period. The effect of longer treatment phases or higher treatment dosage should be explored.

- The generalisation of speech gains in the current study were broadly attributed to the following components of the SML approach (Van der Merwe, 1985; 2011): the use of nonwords containing several easy sounds in CVCV syllable structure as treatment stimuli, blocked practice of nonwords, variable practice of sounds in different phonetic contexts, implementation of a response delay, and use of augmented feedback. Future research could explore different components of the SML approach more explicitly, so as to identify which components are central to the success of the approach and to optimise the treatment "package."

- The probe stimuli used in this study examined generalisation of treatment effects to untrained non- and real-words. Performance on treatment stimuli during the treatment period (acquisition effects) was not measured. Such acquisition measures could be included in future studies to better understand the effects of the SML approach on treatment targets. Furthermore, generalisation of treatment gains to connected speech may also be examined to determine the effect of the SML approach on functional communication.

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- The results of the study indicate that improvements in speech production were maintained up to two weeks post-treatment. However, the variability observed during treatment probes and the downward trend during follow-up for Set 1 real words, makes it uncertain whether treatment effects and generalisation of improved motor planning skills would have been maintained for longer than two weeks post-treatment. Longer maintenance periods of one, three and six months would be useful to confirm that the SML approach (Van der Merwe, 1985; 2011) results in long term improvements in speech production for children with CAS. The effect of normal development may, however, render such an endeavour invalid, as it may compromise the validity and reliability of the data.

- The post-hoc analysis of error types was analysed descriptively as an initial exploration of the effect of the SML treatment on the nature of errors. In future, statistical analyses of the average number of errors per error category should be performed to determine whether the differences in average errors over time are significant.

- The current study was a Phase II study which provides Level IIb evidence for the SML approach. Following further Phase II research to determine the ideal conditions for the SML approach, Phase III research should be conducted to determine the efficacy of this approach under these conditions. Thereafter, the effectiveness under average conditions, and the efficiency of the SML approach should be tested. Higher levels of evidence should be pursued over time, particularly cohort, case-control studies and randomised control trials.

5. Final conclusions

Past literature on childhood apraxia of speech reflects diverse, and often contradicting, views on the diagnosis and treatment of the disorder. In recent years, progress has been made in refining our understanding of the disorder, its symptoms and its treatment. The current study applied the SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) to the treatment of a child with CAS and found a significantly positive change in the child's speech production. This Phase II study, therefore, contributes to the growing literature on the treatment of CAS and proposes the SML approach (Van der Merwe & Tesner, 2000; Van der Merwe, 1985; 2007; 2011) as a promising and effective approach to the treatment of CAS.

6. Summary of Chapter 4

Chapter 4 has presented the conclusions of this investigation and the implications of the findings for researchers and clinicians. A number of limitations and recommendations for future research were also discussed.

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Appendix A: Ethical clearance letters

Faculty of Humanities
Research Ethics Committee

9 October 2013

Dear Prof van der Merwe,

Project:	**Perceptual and acoustic parameters of speech production in childhood apraxia of speech: the effects of speech motor learning treatment**
Researcher:	**M Steyn**
Supervisor:	**Prof A van der Merwe**
Department:	**Communication Pathology**
Reference number:	**28200862**

Thank you for the well written and interesting research proposals that was submitted for review.

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 9 October 2013. Data collection may therefore commence.

Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should your actual research depart significantly from the proposed research, it will be necessary to apply for a new research approval and ethical clearance.

The Committee requests you to convey this approval to the researcher.

We wish you success with the project.

Sincerely

Prof. Sakhela Buhlungu
Chair: Research Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: sakhela.buhlungu@up.ac.za

Research Ethics Committee Members: Dr L Blokland; Prof S Buhlungu (Chair); Prof M-H Coetzee; Dr JEH Grobler; Prof KL Harris; Ms H Klopper; Prof A Mlambo, Dr C Panebianco-Warrens; Prof GM Spies; Prof E Taljard ; Dr FG Wolmarans, Dr P Wood

Our Ref: 28200862

27 August 2014

Miss M Steyn
PO Box 12643
QUEENSWOOD
0121

Dear Miss Steyn

TITLE REGISTRATION: FIELD OF STUDY –   MCOMMUNICATION PATHOLOGY

I have pleasure in informing you that the following has been approved:

TITLE: **Perceptual parameters of speech production in childhood apraxia of speech: The effects of speech motor learning treatment**

SUPERVISOR: **Prof A van der Merwe**

CO-SUPERVISOR: **Prof D Kendall**

I would like to draw your attention to the following:

1.   **ENROLMENT PERIOD**
   (a)   You must be enrolled as a student for at least one academic year before submission of your dissertation/essay.
   (b)   Your enrolment as a student must be renewed annually before 31 March, until you have complied with all the requirements for the degree. You will only be able to have supervision if you provide a proof of registration to your supervisor.

2.   **APPROVAL FOR SUBMISSION**
   On completion of your dissertation/essay enough copies for each examiner must be submitted to Student Administration, together with the prescribed examination enrolment form signed by you, which includes a statement by your director of studies that he/she approves of the submission of your dissertation/essay.

3.   **NOTIFICATION BEFORE SUBMISSION**
   You are required to notify me at least three months in advance of your intention to submit your dissertation/essay for examination.

4.   **INSTRUCTIONS REGARDING THE PREPARATION OF THE DISSERTATION/ESSAY AND THE SUMMARY APPEAR ON THE REVERSE SIDE OF THIS LETTER.**

Yours sincerely

for **DEAN: FACULTY OF HUMANITIES**

Appendix B: Consent letters to the Participant's parents

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

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Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Dear Parent

Request for participation in a research project

Title: **PERCEPTUAL PARAMETERS OF SPEECH PRODUCTION IN CHILDHOOD APRAXIA OF SPEECH: THE EFFECTS OF SPEECH MOTOR LEARNING TREATMENT.**

I, Mollie Steyn, am a Master's student at the University of Pretoria. I am required to conduct a research project in fulfilment of my M. Communication Pathology degree. In this study, I intend to explore the effects of treatment (speech therapy) on several characteristics of childhood apraxia of speech (CAS). CAS is a neurological speech sound disorder that occurs in children. There is still uncertainty in the field of speech-language pathology regarding the underlying cause/s of the disorder, its' diagnosis and appropriate treatment options. There are currently only a limited number of studies investigating different treatment options for CAS and the benefits thereof. As part of this research project, I intend to provide therapy to a child with CAS and investigate any changes in speech production over time.

I would like to request your consent to allow your child to participate in this project. Your child's participation will involve two half-hour therapy sessions per week for a period of eight weeks. The Speech Motor Learning (SML) approach (van der Merwe, 2011) will be followed in these therapy sessions. This approach involves repeated practice of identified target speech sounds in non-words and real words. It has been used successfully in the past to treat CAS, as well as the adult form of the disorder

(acquired apraxia of speech – AOS) and other developmental speech disorders. I will also record samples of your child's production of a list of words as assessment stimuli before treatment commences, throughout the duration of the treatment period and on three occasions thereafter. These recordings will be analysed to determine if changes occurred in his speech production over time.

I am willing to remain involved in your child's treatment after the termination of the study, should you request this. You are welcome to discuss the options for this continued involvement with me at any time. Alternatively, both my study supervisor and I will be available for consultation after the termination of the study.

All information and recordings obtained during the study will be kept strictly confidential. Only my study supervisor and I will know your child's name and personal information and this will not be disclosed to others. Participation in this study is voluntary and you, or your child, may withdraw from the study at any time, without any negative consequences. The information and recordings obtained during the study will be stored at the Department of Communication Pathology for a period of 15 years, in compliance with the ethical guidelines of the University of Pretoria. All relevant information and recordings will be destroyed should you, or your child, choose to withdraw from the study.

Your consent and your child's participation will be sincerely appreciated. It will enable me to contribute to our understanding of CAS and the effects of treatment on some of its' key features. This, in turn, will assist speech-language therapists in making informed decisions about the appropriate and effective treatment of CAS.

The results of the study will be presented in a Master's dissertation, as well as in an article in a scientific journal. You are welcome to inform me if you would like to receive a copy of the research findings.

Should you require any additional information, please contact me on 076 847 5558 or mollie.steyn@up.ac.za.

Kind regards,

_____

Miss Mollie Steyn

M. Communication Pathology (Speech-Language Pathology) student

_____

Prof. Anita van der Merwe

Study Supervisor

_____

Prof. Bart Vinck

HEAD: Department of Speech-Language Pathology and Audiology

University of Pretoria
PRETORIA 0002
Republic of South Africa

Tel: 012 420 2357   anita.vandermerwe@up.ac.za
Fax: 012 420 3517   www.up.ac.za

I, _____ (parent), hereby give my consent that my child, _____ may participate in this research study. I am informed about, and understand, the following:

- My child will be receiving weekly speech therapy, following the Speech Motor Learning (SML) approach (van der Merwe, 2011 in *Aphasiology, vol 25, issue 10*), for a period of eight weeks.
- Regular audio recordings of my child's speech production will be made and later analysed.
- My child's information and recordings will be stored at the Department of Speech-Language Pathology and Audiology for 15 years.
- All information and recordings will be treated with confidentiality and my child's name and personal information will not be made known to any person besides the researcher and the study supervisor.
- Participation in this is voluntary and my child, or I, may withdraw from the study at any time.

Signed: _____

Date: _____

University of Pretoria   Tel: 012 420 2357   anita.vandermerwe@up.ac.za
PRETORIA 0002   Fax: 012 420 3517   www.up.ac.za
Republic of South Africa

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Faculty of Humanities
Department of Speech Language Pathology and Audiology

NAME: _____   DATE: _____

SURNAME: _____

INFORMED CONSENT: Ongoing Clinical Research at the Department of Speech-Language Pathology and Audiology

Dear Client/Parent

The clinics at the Department of Speech-Language Pathology and Audiology, University of Pretoria, aim to deliver the best possible service to our clients. To ensure this, the institution places a high premium on monitoring and improving services through research activities. The department is therefore interested in using all data collected during assessments and intervention sessions. All data will, however, only be used with your permission and under the strictest confidentiality. No names or any identifying information will be released. Data will be coded and each participant will be assigned a code to ensure confidentiality. Processed data may be used for teaching purposes or may be presented at conferences or published in article format. Data will be stored for a minimum of 10 years according to the University of Pretoria's regulations.

Should you consent to the departmental request:

Please complete the following

I _____ hereby acknowledge and agree to the above stipulations regarding the use of my and my family's clinical data for research purposes at the Speech-Language Pathology and Audiology Department.

_____   _____
Signature   Date

Sincerely

Professor Bart Vinck
HEAD: DEPT OF SPEECH-LANGUAGE PATHOLOGY AND AUDIOLOGY

Appendix C: Consent letter to the Participant's private speech-

language therapist

Faculty of Humanities
Department of Speech-Language Pathology and Audiology

Dear Speech-Language Therapist,

Request for participation in a research project
Title: **PERCEPTUAL PARAMETERS OF SPEECH PRODUCTION IN CHILDHOOD APRAXIA OF SPEECH: THE EFFECTS OF SPEECH MOTOR LEARNING TREATMENT.**

I, Mollie Steyn, am a Master's student at the University of Pretoria. I am required to conduct a research project in fulfilment of my M. Communication Pathology degree. In this study, I intend to explore the effects of treatment on several characteristics of childhood apraxia of speech (CAS). CAS is a neurological speech sound disorder that occurs in children and involves a deficit in the motor planning/programming of speech. There is still uncertainty in the field of speech-language pathology regarding the underlying cause/s of the disorder, its' diagnosis and appropriate treatment options. There are currently only a limited number of studies investigating different treatment approaches for CAS and the benefits thereof. As part of this research project, I would like to provide therapy to a child with CAS and investigate any changes in speech production over time.

A client of yours has been identified as a candidate for this study. The client's parents have given informed consent for him to participate in the study. I would also like to request your consent to include him in my study, as well as your inclusion as co-therapist for the duration of the treatment phase.

The client's participation will involve two half-hour therapy sessions per week for a period of eight weeks. The Speech Motor Learning (SML) approach (van der Merwe, 2011) will be followed in these therapy sessions. This approach involves repeated practice of identified target speech sounds in systematically varied phonetic contexts. It has been used successfully in the past to treat CAS, as well as acquired

apraxia of speech (AOS) and other developmental speech disorders. I will also record samples of the client's production of a list of words as probe stimuli before treatment commences (baseline phase), throughout the duration of the treatment phase and on three occasions thereafter (maintenance phase). These recordings will be analysed perceptually to determine if any changes occurred in his speech production over time.

I would like to ask you to conduct the therapy according to the SML approach, together with me, during the eight-week treatment phase. To ensure that experimental control is maintained, I will provide guidance during therapy sessions, monitor the procedures followed and track the client's progress. Both video and audio recordings will be made of each therapy session, with your consent, and may be reviewed by my supervisor.

I have informed the client's parents that I am willing to remain involved in his treatment after the termination of the study, should they request this and should you agree. Alternatively, both my study supervisor and I will be available for consultation after the termination of the study.

All information and recordings obtained during the study will be kept strictly confidential. Only my study supervisor and I will know your and the client's names and personal information, and this will not be disclosed to others. Participation in this study is voluntary and you may withdraw from the study at any time, without any negative consequences. The information and recordings obtained during the study will be stored at the Department of Speech-Language Pathology and Audiology for a period of 15 years, in compliance with the ethical guidelines of the University of Pretoria.

Your consent and involvement in this study will be sincerely appreciated. It will enable me to contribute to our understanding of CAS and the effects of treatment on some of its' key features. This, in turn, will assist other speech-language therapists in making informed decisions about the appropriate and effective treatment of CAS.

University of Pretoria   Tel: 012 420 2357   anita.vandermerwe@up.ac.za
PRETORIA 0002   Fax: 012 420 3517   www.up.ac.za
Republic of South Africa

The results of the study will be presented in a Master's dissertation, as well as in an article in a scientific journal. You are welcome to inform me if you would like to receive a copy of the research findings.

Should you require any additional information, please contact me on 076 847 5558 or mollie.steyn@up.ac.za.

Kind regards,

_____

Miss Mollie Steyn

M. Communication Pathology (Speech-Language Pathology) student

_____

Prof. Anita van der Merwe

Study Supervisor

_____

Prof. Bart Vinck

HEAD: Department of Speech-Language Pathology and Audiology

I, _____ (speech-language therapist), hereby give my consent that my client, _____ may participate in this research study. I also agree to continue in my role as the client's speech-language therapist, with the researcher acting as co-therapist to ensure experimental control is maintained. I am informed about, and understand, the following:

- – The client will be receiving weekly speech therapy, following the Speech Motor Learning (SML) approach (van der Merwe, 2011 in *Aphasiology, vol 25, issue 10*), for a period of eight weeks.
- – The researcher and the study supervisor may monitor this speech therapy for the duration of the treatment phase.
- – Regular video and audio recordings of the client's speech production will be made and later analysed.
- – The client's information and recordings will be stored at the Department of Speech-Language Pathology and Audiology for 15 years.
- – All information and recordings will be treated with confidentiality and neither my own, nor my client's name and personal information will be made known to any person besides the researcher and the study supervisor.
- – Participation in this is voluntary and I, or my client, may withdraw from the study at any time.

Signed: _____

Date: _____

University of Pretoria   Tel: 012 420 2357   anita.vandermerwe@up.ac.za
PRETORIA 0002   Fax: 012 420 3517   www.up.ac.za
Republic of South Africa

Appendix D: Consent letter to the pre-school

Dear Sir or Madam

Request for participation in a research project

Title: **PERCEPTUAL PARAMETERS OF SPEECH PRODUCTION IN CHILDHOOD APRAXIA OF SPEECH: THE EFFECTS OF SPEECH MOTOR LEARNING TREATMENT.**

I, Mollie Steyn, am a Master's student at the University of Pretoria. I am required to conduct a research project in fulfilment of my M. Communication Pathology degree. In this study, I intend to explore the effects of treatment on several characteristics of childhood apraxia of speech (CAS). CAS is a neurological speech sound disorder that occurs in children and involves a deficit in the motor planning/programming of speech. There is still uncertainty in the field of speech-language pathology regarding the underlying cause/s of the disorder, its' diagnosis and appropriate treatment options. There are currently only a limited number of studies investigating different treatment approaches for CAS and the benefits thereof. As part of this research project, I would like to provide therapy to a child with CAS and investigate any changes in speech production over time.

A child who currently receives private speech therapy at The Talk Shop, has been identified as a candidate for this study. The child has been diagnosed with CAS and his parents have given informed consent for him to participate in the study. I would like to request your consent to include him in my study, as well as the private speech-language therapist as co-therapist for the duration of the treatment phase. I also request your consent to conduct the therapy, together with the speech-language therapist, at The Talk Shop.

The child's participation will involve two half-hour therapy sessions per week for a period of eight weeks. The Speech Motor Learning (SML) approach (van der Merwe,

2011) will be followed in these therapy sessions. This approach involves repeated practice of identified target speech sounds in systematically varied phonetic contexts. It has been used successfully in the past to treat CAS, as well as acquired apraxia of speech (AOS) and other developmental speech disorders. I will also record samples of the child's production of a list of words as probe stimuli before treatment commences (baseline phase), throughout the duration of the treatment phase and on three occasions thereafter (maintenance phase). These recordings will be analysed perceptually to determine if any changes occurred in his speech production over time.

The speech-language therapist has been asked to conduct the therapy according to the SML approach, together with me, during the eight-week treatment phase. To ensure that experimental control is maintained, I will provide guidance during therapy sessions, monitor the procedures followed and track the child's progress. Both video and audio recordings will be made of each therapy session and may be reviewed by my supervisor.

All information and recordings obtained during the study will be kept strictly confidential. Only my study supervisor and I will know the child's and the speech-language therapist's names and personal information, and this will not be disclosed to others. Information related to The Talk Shop and its' employees will also not be disclosed. Participation in this study is voluntary and the child, his parents and the speech-language therapist may withdraw from the study at any time, without any negative consequences. The information and recordings obtained during the study will be stored at the Department of Speech-Language Pathology and Audiology for a period of 15 years, in compliance with the ethical guidelines of the University of Pretoria.

Your consent and support in this study will be sincerely appreciated. It will enable me to contribute to our understanding of CAS and the effects of treatment on some of its' key features. This, in turn, will assist other speech-language therapists in making informed decisions about the appropriate and effective treatment of CAS.

The results of the study will be presented in a Master's dissertation, as well as in an article in a scientific journal. You are welcome to inform me should you would like to receive a copy of the research findings.

Should you require any additional information, please contact me on 076 847 5558 or mollie.steyn@up.ac.za.

Kind regards,

_____

Miss Mollie Steyn

M. Communication Pathology (Speech-Language Pathology) student

_____

Prof. Anita van der Merwe

Study Supervisor

_____

Prof. Bart Vinck

HEAD: Department of Speech-Language Pathology and Audiology

University of Pretoria   Tel: 012 420 2357   anita.vandermerwe@up.ac.za
PRETORIA 0002   Fax: 012 420 3517   www.up.ac.za
Republic of South Africa

I, _____ (Head: The Pre-school), hereby give my consent that the client, _____ and the speech-language therapist _____ may participate in this research study. I am informed about, and understand, the following:

- The client will be receiving weekly speech therapy, following the Speech Motor Learning (SML) approach (van der Merwe, 2011 in *Aphasiology, vol 25, issue 10*), for a period of eight weeks.

- The researcher and the study supervisor may monitor this speech therapy for the duration of the treatment phase.

- The speech therapy will be conducted on The Talk Shop premises.

- Regular video and audio recordings of the client's speech production will be made and later analysed.

- The client's information and recordings will be stored at the Department of Speech-Language Pathology and Audiology for 15 years.

- All information and recordings will be treated with confidentiality and neither the speech-language therapist's, nor the client's name and personal information will be made known to any person besides the researcher and the study supervisor. Information relating to The Talk Shop will not be disclosed.

- Participation in this study is voluntary and the speech-language therapist, the client, or his parents may withdraw from the study at any time.

Signed: _____

Date: _____

Appendix E: Examples of treatment stimuli

Examples of treatment stimuli implemented in the current study.

Target sounds	Examples of treatment stimuli					Treated
Consonants (C): b, m, n, t	*Variation level 1* C1 V1 C1 V+	bibi bibu bibɔ bibɛ bibæ	mumi mumu mumɔ mumɛ mumæ	nɔni nɔnu nɔnɔ nɔnɛ nɔnæ	tɛti tɛtu tɛtɔ tɛtɛ tɛtæ	Yes
Vowels (V): i, u, ɔ, ɛ, æ	*Variation level 2* C1 V1 C2 V+	bæmi bæmu bæmɔ bæmɛ bæmæ	mɔti mɔtu mɔtɔ mɔtɛ mɔtæ	nɛbi nɛbu nɛbɔ nɛbɛ nɛbæ	tuni tunu tunɔ tunɛ tunæ	Yes
	Variation level 3 C1 V1 C+ V1	bɛbɛ bɛmɛ bɛnɛ bɛtɛ	mæbæ mæmæ mænæ mætæ	nubu numu nunu nutu	tibi timi tini titi	No
	Variation level 4 C1 V+ C2 V1	binɔ bunɔ bonɔ bɛnɔ bænɔ	mibɛ mubɛ mɔbɛ mɛbɛ mæbɛ	niti nuti nɔti nɛti næti	timæ tɛmæ tomæ tɛmæ tæmæ	No
	Variation level 5 C1 V+ C+ V+	bɛtu bɔmɛ bæmɛ bɛtɛ bubɔ	mænæ mɛni mɛmɛ mɛti mumɔ	nɔti nitɔ numɛ nɛnɛ nætu	tɛbæ tænɔ totæ tæbɛ tæbu	No

Notes: Treatment stimuli for the Participant in this study were generated in series' of CVCV nonwords. Phonetic variation increases hierarchically from Variation level 1 (only the final vowel varies) to Variation level 5 (both vowels and the second consonant varies). Only Variation level 1 and 2 were treated in the 9-week treatment period. C = consonant, V = vowel, + indicates variation of sound across a series of nonwords (see Van der Merwe, 2011, for an explanation and justification of the levels of variation between sounds in nonwords).

Appendix F: Raw data

Raw data 1. Analysis of the Participant's spontaneous speech sample: Consonants. 1 = correct, 0 = incorrect (distorted, substituted or omitted).

Consonant	p	b	t	d	k	g	m	n	ŋ	f	v	θ	ð	s	z	ʃ	ʒ	h	ʔ	tʃ	dʒ	w	l	ɹ	j	
	0	1	0	0	0	0	1	0		0			0	0	0	1		0	1	0		1		0	0	
	0	1	1	1	0	0	1	1		0			0	0	0	1		0		1		1		0	0	
	0	1	1	1	0	0	0	0		0			0	0	0	0		0		1		1		0	0	
	1	0	0	1	0	0	0	0					0	0				0				1		0	1	
	0	1	1	0	0	0	0	1					0	0				0				0		0	1	
	1	1	0	0	0	0	1	1					0	0				0				1		0		
	1	1	0	0	0	0	1	1					0	0				1				1		0		
	1	1	0	1	0		1	1					0	0				0				0		0		
	1	1	1	0	0		1	1					0	0				0				1		0		
	1	0	1	1	0		1	1					0	0				1				1		0		
	1	1	1	0			1	1						0				1				1		0		
	0	1	1	1			1	1						0				1				1		0		
	1	1	0	1			1							0				1				0				
	1	1	0	0			1							0				1				1				
	1	0	1	1			1							0				0				1				
	1	1	1	0			1							0				1				1				
	0	1	1	1			1							0								1				
	0	1	1	1			1																			
	1	1	1	0			1																			
	1	0	0	1			0																			
	1	0	1	0			1																			
	1	0	0	1			1																			
	0	0	1	0			1																			
	0	1	0	1			0																			
	1	1	1	1			1																			
	0	1	0	0			1																			
	1	1	0	0			0																			
	0	1	0	0			1																			
	1	1	0	0			1																			
	1	1	1	0			1																			

Consonant	p	b	t	d	k	g	m	n	ŋ	f	v	θ	ð	s	z	ʃ	ʒ	h	ʔ	tʃ	dʒ	w	l	ɹ	j	
	1	1	1	0			1																			
	0	0	1	1			1																			
	1	0	1	1			1																			
	0	1	1	1			0																			
	1	1	1	1			1																			
	0	0	0	1			0																			
	0	1	1	1			1																			
	0	1	1	1			1																			
		1	1	1			0																			
		1	1	1			1																			
		0	1	1			0																			
		1	0	0			1																			
		1	1	1			1																			
		1	1	1			1																			
		1	0	1			1																			
		0	0	1			1																			
		1		1			1																			
		1		0			1																			
		0		0			1																			
		1		1			1																			
		1		0			1																			
		1		1			0																			
		1		0			1																			
		1		0																						
				0																						
				1																						
Total correct (A)	22	41	28	32	0	0	42	9	0	0	0	0	0	0	0	2	0	7	1	2	0	14	0	0	2	**202**
# opportunities (B)	38	54	46	56	10	7	53	12	0	3	0	0	10	17	3	3	0	16	1	3	0	17	0	12	5	
Frequency (A/202)	11%	20%	14%	16%	0.0%	0.0%	21%	4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1%	0.0%	3%	0.5%	1%	0.0%	7%	0.0%	0.0%	1%	
Accuracy (A/B)	58%	76%	61%	57%	0%	0%	79%	75%	0%	0%	0%	0%	0%	0%	0%	67%	0%	44%	100%	67%	0%	82%	0%	0%	40%	

Raw data 2. Analysis of the Participant's spontaneous speech sample: Vowels, diphthongs or rhotics. 1 = correct, 0 = incorrect (distorted, substituted or omitted).

Vowel / diphthong	iː	ɪ	ɛ	æ	ə	ʌ	ɑ	ʊ	uː	ɔ	ɒ	əɪ	əʊ	ɑʊ	iʊ	ɪə	aɪ	aːɪ	ɔɪ	ɝ	ɚ	
	1	0	1	1	1	1	1	1	1	1	1		1	1	0	0	1			0	0	
	1	1	1	1	1	1	0	1	1	1	1		1	1		0	1				0	
	1	1	1	1	1	1	1	1	1	1	1		0	0		0	0					
	1	0	1	0	0	1	1	1	1	1	1		1	0		0	1					
	1	1	0	1	0	0	1	1	1	1	1		1	1		1	1					
	1	1	1	1		1	1	1	1	1	1		0	1		0	1					
	1	1	1	1		1	1	0	1	1	1		0	1		0	0					
	1	1	0	1		1	1	1	1	1	1		1			0	1					
	1	0	1	1		1	1	1	1	1	1		1			1						
	1	0	1	1		1	1	1	1	1	1		1			1						
	0	1	1	1		1		1	1	1	1		0			1						
	0		1	1		1		1	0	1	1		1			1						
	1		1	1		1		1	1	1	1		1			0						
	1		1	1		1		1	1	1	1		1			1						
	1		1	1		1		1	1	1	1		0									
	1		1	1		0		1	1	1	1		0									
	1		1	1		1				1	1											
	1		1	0		0				1												
	1		1	1		1				1												
	1		1			1				1												
	1		1			1				1												
			1			1				1												

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Vowel / diphthong	iː	ɪ	ɛ	æ	ə	ʌ	ɑ	ʊ	uː	ɔ	ɒ	əɪ	əʊ	ɑʊ	iʊ	ɪə	aɪ	aːɪ	ɔɪ	ɜ	ə	
			0			1				1												
			1			1				0												
			1			0				1												
			1			1				1												
			0			1				0												
			1			1				1												
			1			1				1												
			1			1				1												
			1			0				1												
			1			1				1												
			0			1				0												
			1			1				0												
			0			1				1												
			0			1				1												
			1			1				1												
			1			1				1												
Total correct (A)	19	7	31	17	3	33	9	15	15	34	17	0	10	5	0	6	6	0	0	0	0	227
# opportunities (B)	21	11	38	19	5	38	10	16	16	38	17	0	16	7	1	14	8	0	0	1	2	
Frequency (A/227)	8%	3%	14%	7%	1%	15%	4%	7%	7%	15%	7%	0%	4%	2%	0%	3%	3%	0%	0%	0%	0%	
Accuracy (A/B)	90%	64%	82%	89%	60%	87%	90%	94%	94%	89%	100%	0%	63%	71%	0%	43%	75%	0%	0%	0%	0%	

Raw data 3. Data analysis: Whole word accuracy

The following research questions were posed: Will treatment effects generalise to untreated non- and real-word stimuli : -
1. Containing only treated age-appropriate consonants and five vowels (Set 1 sounds - b, m, n, t + i, u, ɔ, ɛ, æ).
2. In addition containing three untreated age-appropriate consonants and the same five vowels (Set 2 sounds - d, f, p + b, m, n, t + i, u, ɔ, ɛ, æ).
3. In addition containing three untreated age-inappropriate consonants and the same five vowels (Set 3 sounds - l, s, v + d, f, p + b, m, n, t + i, u, ɔ, ɛ, æ).

Data	Data point nr		Set 1 NW	Set 1 RW		Set 2 NW	Set 2 RW	Set 3 NW	Set 3 RW
A1	B1	Baseline 1	10.0%	0.0%	B1	10.0%	10.0%	0.0%	0.0%
	B2	Baseline 2	40.0%	0.0%	B2	0.0%	11.1%	0.0%	0.0%
	B3	Baseline 3	20.0%	14.3%	B3	10.0%	0.0%	0.0%	0.0%
B	T1	Treatment 1	20.0%	28.6%	B4	30.0%	30.0%	10.0%	0.0%
	T2	Treatment 2	50.0%	42.9%	B5	10.0%	0.0%		
	T3	Treatment 3	40.0%	28.6%	B6	10.0%	10.0%		
	T4	Treatment 4	20.0%	16.7%	B7			0.0%	0.0%
	T5	Treatment 5	40.0%	71.4%	B8	30.0%	10.0%		
	T6	Treatment 6	20.0%	0.0%	B9			0.0%	0.0%
	T7	Treatment 7	60.0%	14.3%	B10	0.0%	0.0%		
	T8	Treatment 8	60.0%	100.0%	B11			0.0%	11.1%
	T9	Treatment 9	50.0%	60.0%	B12	50.0%	30.0%		
A2	F1	1-wk post	70.0%	85.7%	B13	10.0%	50.0%	0.0%	0.0%
	F2	2-wk post	80.0%	71.4%	B14	20.0%	40.0%	10.0%	0.0%
		Mean A1	0.23	0.05		0.07	0.07	0.00	0.00
		Mean A2	0.75	0.79		0.15	0.45	0.05	0.00
		A2-A1	0.52	0.74		0.08	0.38	0.05	0.00
		SD A1	0.15	0.08		0.06	0.06	0.00	0.00
		ES	3.38	8.95		1.44	6.20	#DIV/0!	#DIV/0!
	Set 3	Adjusted SD A1						0.11	0.07
		ES						0.48	0.00

Raw data 4. Post-hoc data analysis: Nature of errors, Set 1.

How may improvement affect the nature of errors over the course of the study?								
* Phonetic-motoric errors: Consonant distortions, voice onset time (VOT) errors								
* Ambiguous errors: Substitutions and distorted substitutions of consonants, all vowel errors								
* Phonological errors: Additions, omissions, and trans-positionings								
Raw scores								
		Set 1 nonwords (NW)				Set 1 real words (RW)		
		Phonetic-motoric	Ambiguous	Phonological	TOTAL ERRORS	Phonetic-motoric	Ambiguous	Phonological	TOTAL ERRORS
B1	Baseline 1	9	9	0	18	9	3	1	13
B2	Baseline 2	2	5	0	7	8	2	0	10
B3	Baseline 3	6	3	0	9	6	8	0	14
T1	Treatment 1	8	4	0	12	7	1	0	8
T2	Treatment 2	5	2	0	7	4	0	0	4
T3	Treatment 3	4	3	0	7	4	3	0	7
T4	Treatment 4	9	2	0	11	4	2	1	7
T5	Treatment 5	4	3	0	7	1	1	0	2
T6	Treatment 6	11	11	0	22	6	3	0	9
T7	Treatment 7	4	5	0	9	5	4	0	9
T8	Treatment 8	3	1	0	4	0	0	0	0
T9	Treatment 9	3	4	0	7	2	0	0	2
P1	1-wk post	3	2	0	5	1	0	0	1
P2	2-wk post	2	1	0	3	1	1	0	2
Number of errors per category / total errors per NW or RW set								
B1	Baseline 1	50.0%	50.0%	0.0%		69.2%	23.1%	7.7%	
B2	Baseline 2	28.6%	71.4%	0.0%		80.0%	20.0%	0.0%	
B3	Baseline 3	66.7%	33.3%	0.0%		42.9%	57.1%	0.0%	
T1	Treatment 1	66.7%	33.3%	0.0%		87.5%	12.5%	0.0%	
T2	Treatment 2	71.4%	28.6%	0.0%		100.0%	0.0%	0.0%	
T3	Treatment 3	57.1%	42.9%	0.0%		57.1%	42.9%	0.0%	
T4	Treatment 4	81.8%	18.2%	0.0%		57.1%	28.6%	14.3%	
T5	Treatment 5	57.1%	42.9%	0.0%		50.0%	50.0%	0.0%	
T6	Treatment 6	50.0%	50.0%	0.0%		66.7%	33.3%	0.0%	
T7	Treatment 7	44.4%	55.6%	0.0%		55.6%	44.4%	0.0%	
T8	Treatment 8	75.0%	25.0%	0.0%		No errors	No errors	No errors	
T9	Treatment 9	42.9%	57.1%	0.0%		100.0%	0.0%	0.0%	
F1	1-wk post	60.0%	40.0%	0.0%		100.0%	0.0%	0.0%	
F2	2-wk post	66.7%	33.3%	0.0%		50.0%	50.0%	0.0%	
Ave nr of errors per error category for each NW or RW set/Ave nr of total errors per NW or RW set for each phase								
B1 -B3	Baseline	50.0%	50.0%	0.0%		62.2%	35.1%	2.7%	
F1-F2	Follow-up	62.5%	37.5%	0.0%		66.7%	33.3%	0.0%	

Raw data 5. Post-hoc data analysis: Nature of errors, Set 2.

How may improvement affect the nature of errors over the course of the study?								
* Phonetic-motoric errors: Consonant distortions, voice onset time (VOT) errors								
* Ambiguous errors: Substitutions and distorted substitutions of consonants, all vowel errors								
* Phonological errors: Additions, omissions, and trans-positionings								
Raw scores								
		Set 2 nonwords (NW)				Set 2 real words (RW)		
		Phonetic-motoric	Ambiguous	Phonological	TOTAL ERRORS	Phonetic-motoric	Ambiguous	Phonological	TOTAL ERRORS
B1	Baseline 1	9	6	0	15	10	2	2	14
B2	Baseline 2	13	8	1	22	11	2	0	13
B3	Baseline 3	9	11	0	20	13	4	0	17
B4	Baseline 4	7	5	0	12	6	4	0	10
B5	Baseline 5	8	7	0	15	12	3	0	15
B6	Baseline 6	12	4	0	16	11	7	0	18
B7	Baseline 7								
B8	Baseline 8	9	3	0	12	10	2	0	12
B9	Baseline 9								
B10	Baseline 10	8	5	0	13	10	2	0	12
B11	Baseline 11								
B12	Baseline 12	2	4	0	6	6	3	0	9
B13	Baseline 13	8	8	1	17	7	2	0	9
B14	Baseline 14	5	6	0	11	5	2	0	7
Number of errors per category / total errors per NW or RW set								
B1	Baseline 1	60.0%	40.0%	0.0%		71.4%	14.3%	14.3%	
B2	Baseline 2	59.1%	36.4%	4.5%		84.6%	15.4%	0.0%	
B3	Baseline 3	45.0%	55.0%	0.0%		76.5%	23.5%	0.0%	
B4	Baseline 4	58.3%	41.7%	0.0%		60.0%	40.0%	0.0%	
B5	Baseline 5	53.3%	46.7%	0.0%		80.0%	20.0%	0.0%	
B6	Baseline 6	75.0%	25.0%	0.0%		61.1%	38.9%	0.0%	
B7	Baseline 7								
B8	Baseline 8	75.0%	25.0%	0.0%		83.3%	16.7%	0.0%	
B9	Baseline 9								
B10	Baseline 10	61.5%	38.5%	0.0%		83.3%	16.7%	0.0%	
B11	Baseline 11								
B12	Baseline 12	33.3%	66.7%	0.0%		66.7%	33.3%	0.0%	
B13	Baseline 13	47.1%	47.1%	5.9%		77.8%	22.2%	0.0%	
B14	Baseline 14	45.5%	54.5%	0.0%		71.4%	28.6%	0.0%	
Ave nr of errors per error category for each NW or RW set/Ave nr of total errors per NW or RW set for each phase								
B1-B3	Basline 1-3	54.4%	43.9%	1.8%		77.3%	18.2%	4.5%	
B13-B14	Basline 13-14	46.4%	50.0%	3.6%		75.0%	25.0%	0.0%	

Raw data 6. Post-hoc data analysis: Nature of errors, Set 3.

How may improvement affect the nature of errors over the course of the study?									
* Phonetic-motoric errors: Consonant distortions, voice onset time (VOT) errors									
* Ambiguous errors: Substitutions and distorted substitutions of consonants, all vowel errors									
* Phonological errors: Additions, omissions, and trans-positionings									
Raw scores									
		Set 3 nonwords (NW)				Set 3 real words (RW)			
		Phonetic-motoric	Ambiguous	Phonological	TOTAL ERRORS	Phonetic-motoric	Ambiguous	Phonological	TOTAL ERRORS
B1	Baseline 1	9	12	0	21	7	4	0	11
B2	Baseline 2	15	7	0	22	6	6	1	13
B3	Baseline 3	15	5	1	21	7	7	0	14
B4	Baseline 4	5	8	0	13	7	6	2	15
B5	Baseline 5								
B6	Baseline 6								
B7	Baseline 7	9	6	0	15	10	2	5	17
B8	Baseline 8								
B9	Baseline 9	12	12	0	24	12	13	6	31
B10	Baseline 10								
B11	Baseline 11	11	5	0	16	11	2	6	19
B12	Baseline 12								
B13	Baseline 13	9	5	1	15	9	7	5	21
B14	Baseline 14	9	4	0	13	7	14	2	23
Number of errors per category / total errors per NW or RW set									
B1	Baseline 1	42.9%	57.1%	0.0%		63.6%	36.4%	0.0%	
B2	Baseline 2	68.2%	31.8%	0.0%		46.2%	46.2%	7.7%	
B3	Baseline 3	71.4%	23.8%	4.8%		50.0%	50.0%	0.0%	
B4	Baseline 4	38.5%	61.5%	0.0%		46.7%	40.0%	13.3%	
B5	Baseline 5								
B6	Baseline 6								
B7	Baseline 7	60.0%	40.0%	0.0%		58.8%	11.8%	29.4%	
B8	Baseline 8								
B9	Baseline 9	50.0%	50.0%	0.0%		38.7%	41.9%	19.4%	
B10	Baseline 10								
B11	Baseline 11	68.8%	31.3%	0.0%		57.9%	10.5%	31.6%	
B12	Baseline 12								
B13	Baseline 13	60.0%	33.3%	6.7%		42.9%	33.3%	23.8%	
B14	Baseline 14	69.2%	30.8%	0.0%		30.4%	60.9%	8.7%	
Ave nr of errors per error category for each NW or RW set/Ave nr of total errors per NW or RW set for each phase									
B1-B3	Basline 1-3	60.9%	37.5%	1.6%		52.6%	44.7%	2.6%	
B13-B14	Basline 13-14	64.3%	32.1%	3.6%		36.4%	47.7%	15.9%	