CHAPTER THREE
SPEECH AND LANGUAGE PROCESSING IN APRAXIA OF SPEECH: DEFINITION, DIFFERENTIATION AND THE INFLUENCE OF CONTEXTUAL FACTORS

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CHAPTER THREE
SPEECH AND LANGUAGE PROCESSING IN APRAXIA OF SPEECH: DEFINITION, DIFFERENTIATION AND THE INFLUENCE OF CONTEXTUAL FACTORS

3.1 INTRODUCTION

The framework of speech sensorimotor control, proposed by Van der Merwe (1997), depicts speech production as being context-sensitive with the implication that contextual factors influence the processes involved in speech sensorimotor control. Speech production as a context-sensitive phenomenon consequently requires that adjustments be made regarding the control strategies employed by the brain depending on the context in which speech is produced, in other words, depending on the processing demands imposed by the context (Van der Merwe, 1997). Although a normal speaker can easily adapt to different contextual demands, persons exhibiting difficulty regarding any of the stages involved in speech and language processing, for example, persons with AOS who have difficulty regarding the motor planning of speech, might not be as flexible regarding adaptation to increased contextual demands. Consequently perceptually accurate speech might not be achieved by these speakers when the processing demands are increased. Van der Merwe (1997) emphasizes the importance of determination of the influence of all the identified contextual factors on the different phases of the speech production process, since this will impact on both treatment and research results. Through the study of the influence of contextual factors on speech production in AOS, more can be learnt about the underlying nature of this disorder and pathological speech motor control under circumstances of increased processing demand.

In this chapter, AOS will be defined. Furthermore, the deficit in persons exhibiting a preponderance of literal or PPs will be defined to differentiate between PP and AOS since, unlike those with AOS, persons with PP are believed to exhibit a breakdown at a distinct level of the speech production process (McNeil *et al.*, 1997; Van der Merwe, 1997). In the study of AOS, the inclusion of persons with PP has the potential to assist with differential diagnosis and reveal more about the nature of AOS. Models,

theories and frameworks proposed for explanation of AOS will be reviewed in an attempt to explain the underlying deficit in AOS. Where applicable, the emphasis which these models place on the influence of contextual factors on speech production will be highlighted. Aspects of speech timing which are studied in an attempt to learn more about the underlying nature and characteristics of AOS and PP will be discussed, whereafter the effect of different contextual factors on speech production in persons with AOS will be reviewed. From this discussion, the importance of studying the influence of contextual factors, specifically L1 versus L2 production and speech rate alterations, on the temporal parameters of speech production in AOS and PP, will be motivated.

3.2 DEFINING APRAXIA OF SPEECH

Clarification of the nature of neurogenic speech disorders is vitally important, not only for diagnosis and treatment of these disorders, but also for providing significant information concerning normal and pathologic speech motor control (Itoh & Sasanuma, 1984). The first step towards clarifying the nature of a specific speech disorder entails defining that disorder. The compiled definition then forms the foundation from where experimental questions are formulated and methods for answering these questions are derived (Rosenbek & McNeil, 1991). Underscoring this issue, Rosenbek and McNeil (1991:289) stated that names and definitions "if carelessly, idiosyncratically, or prematurely chosen...obscure boundaries, disturb or repudiate concepts, and frustrate experimentation".

AOS is a neurogenic speech disorder which has been subject to continuous controversy regarding its underlying nature since the first mention of "aphemia", characterized by selective impairment of articulatory abilities, by Paul Broca in 1861 (Lebrun, 1989). Since then, some researchers have suggested that AOS is a language disorder and have consequently treated it as a type of aphasia (Goodglass, Quadfasel & Timberlake, 1964; Martin, 1974), while others have postulated that it is a type of dysarthria and have labelled it "phonetic disintegration" (Alajouanine, Ombredane & Durand as cited in Mlcoch & Noll, 1980), "apraxic dysarthria" (Natham as cited in Mlcoch & Noll, 1980) and "cortical dysarthria" (Bay, 1962). However, other

researchers proposed that AOS is a motor speech disorder, which can be distinguished from both aphasia and dysarthria (Johns & Darley, 1970). Currently most researchers agree that the nature of AOS is phonetic-motoric (Ballard *et al.*, 2000). However, despite the frequency of AOS, it is still poorly understood and relatively under-researched (Varley & Whiteside, 2001). In the following section the most prominent definitions that have been offered for AOS will be provided and discussed as an introduction, before a perusal of models and theories that attempt to explain the underlying nature and observed characteristics in AOS.

3.2.1 Darley's definition

Darley is recognized as the first researcher who applied the concept of apraxia to speech production (McNeil *et al.*, 1997). Darley in 1969 (as cited in Deal and Darley, 1972:639) defined AOS as follows:

> …an articulatory disorder resulting from impairment, as a result of brain damage, of the capacity to program the positioning of speech musculature and the sequencing of muscle movements for the volitional production of phonemes. The speech musculature does not show significant weakness, slowness, or incoordination when used for reflex and automatic acts. Prosodic alterations may be associated with the articulatory problem, perhaps in compensation for it.

The essence of Darley's definition implies that AOS is a disorder regarding the ability to form vocal tract configurations and to accomplish movement from one vocal tract configuration to the following during the voluntary production of speech (Rosenbek *et al.*, 1984). This inability exists despite the fact that no other motor deficits are evident during the use of these same muscles for other involuntary non-speech movements. In this regard it needs to be mentioned, however, that in recent years, researchers have reported that persons with AOS exhibit motor planning disturbances regarding non-speech movements as well (Clark & Robin, 1998; Hageman, Robin, Moon & Folkins, 1994; McNeil, Weismer, Adams & Mulligan 1990b, Square-Storer, Roy & Hogg, 1990).

Darley's definition is sufficient for diagnostic purposes if it can be specified which behaviors are indicative of a deficit in the ability to form vocal tract configurations and which suggest an inability to accomplish movement from one vocal tract configuration to the next (Rosenbek *et al.*, 1984). Possibly the articulatory search behavior exhibited by persons with AOS during attempted speech production is indicative of these persons' inability to form vocal tract configurations, which in turn could be due to their inability to specify and/or adapt the temporal and spatial motor goals necessary for speech production. In order to form accurate vocal tract configurations the movements of the articulators need to be temporally and spatially controlled. Studying temporal and/or spatial aspects of speech production in AOS, can thus shed light on the motor planning ability of a person with AOS and consequently on the underlying nature of the disorder.

In order to move from one vocal tract position to the next, synchronization of articulatory movements in time and space is needed. Deficits regarding synchronization of articulatory movements could thus possibly result in an inability to accomplish movement from one vocal tract configuration to the next, since temporal overlapping of articulatory movements is needed to accomplish this (Smith, 1992a). It is thus evident that the deficits described by Darley's definition, implicate disruption of temporal and spatial control of movements in persons with AOS. Temporal aspects of speech production can be perceived acoustically and consequently the study of temporal aspects of speech production is potentially important, since it can shed light on the nature of the motor disturbance in AOS. The study of the nature of timing deficits in various neurogenic speech disorders could also assist in differential diagnosis.

3.2.2 Wertz, Rosenbek and LaPointe's definition

Wertz *et al.* (1984:4) slightly modified the definition provided by Darley and defined AOS as follows:

> …a neurogenic phonologic disorder resulting from sensorimotor impairment of the capacity to select, program and/or execute in coordinated and normally timed sequences, the positioning of the speech musculature for the volitional production of speech sounds. The loss or impairment of phonologic rules of the native language is not adequate to explain the observed pattern of deviant speech, nor is the disturbance attributable to weakened or misdirected actions of specific muscle groups. Prosodic alteration, that is changes in stress, intonation, and/or rhythm, may be associated with the articulatory disruption either as a primary part of the condition or in compensation for it.

The definition proposed by Wertz *et al.* (1984) is very similar to the one proposed by Darley (as cited in Deal & Darley, 1972), in that it emphasizes the inability of persons with AOS to position the articulators correctly and timely. This definition also implies disrupted articulatory timing as being a fundamental characteristic of AOS, together with an inability to reach spatial targets. The use of the words "coordinated" and "normally timed sequences" implies the presence of disrupted timing relations among the movements of the articulators, since accurate timing is essential for accomplishment of coordinated movement and normally timed sequences (Keller, 1990). Accurate specification of temporal and spatial parameters, in turn, leads to accomplishment of perceptually accurate speech.

The fact that disrupted timing of articulatory movements is a fundamental characteristic of AOS implies a possible deficit at the level of the motor planning and/or programming of speech, because specification of the temporal parameters for movement of the articulators (planning) and muscles (programming) occurs during these two stages of the speech production process, according to the framework of speech sensorimotor control proposed by Van der Merwe (1997). It is thus not certain why Wertz *et al.* (1984) state that AOS is a *phonologic* disorder, since this implies a deficit at the level of linguistic-symbolic planning (Van der Merwe, 1997). Wertz *et al.* (1984) probably referred to the resulting speech errors or phonological deficits which perceptual judgement of speech errors had revealed. During the time when Wertz *et al.* (1984) compiled their definition, it was generally believed that persons with AOS exhibit predominantly substitutions in their speech. However, phonological errors have since been shown not be the predominant speech

characteristic in AOS (McNeil *et al.*, 1997). Furthermore, the term "phonological" in the definition by Wertz *et al.* (1984) was most probably used in the generic sense, with the implication that it included phonetic and phonological aspects of speech production, as well as overt and covert speech (Shriberg & Kwiatkowski as cited in Van der Merwe, 1986). The use of the term phonological in Wertz *et al.*'s definition might cause unnecessary confusion regarding the nature of the disorder in AOS and it might have been more appropriate to say that AOS is a *motor speech* or *phonetic disorder*. There are researchers, however, who still propose AOS to be a phonological disorder, for example, Dogil and Mayer (1998) who give a linguistic account of AOS.

3.2.3 McNeil et al.'s (1997) definition of apraxia of speech

McNeil *et al.* (1997:329) specify the core features of AOS and characterize the mechanisms involved in this disorder by defining it as follows:

> ...a phonetic-motoric disorder of speech production caused by inefficiencies in the translation of a well-formed and filled phonologic frame to previously learned kinematic parameters assembled for carrying out the intended movement, resulting in intra- and inter-articulator temporal and spatial segmental and prosodic distortions. It is characterized by distortions of segments and intersegment transitionalization resulting in extended durations of consonants, vowels, and time between sounds, syllables, and words. These distortions are often perceived as sound substitutions and as the mis-assignment of stress and other phrasal and sentence-level prosodic abnormalities. Errors are relatively consistent in location within the utterance and invariable in type. It is not attributable to deficits of muscle tone or reflexes, nor to deficits in the processing of auditory, tactile, kinesthetic, proprioceptive, or language information. In its extremely infrequently occurring "pure" form, it is not accompanied by the above listed deficits of motor physiology, perception, or language.

From this definition, it is evident that these researchers support the notion that the underlying nature of AOS is phonetic-motoric, whilst the phonological level of the speech production process is believed to be intact. McNeil *et al.* (1997) also make mention of the aberrant temporal and spatial parameters of speech production resulting in distortion and prolonged durations. Prolonged durations are one component of temporal disruption and appear to be an integral part of the symptomatology in AOS.

3.2.4. Conclusion regarding definitions of apraxia of speech

A common theme which emerges from the above three definitions, is the difficulty persons with AOS of speech experience with specification and control of the spatial and temporal parameters of speech production. As discussed in chapter two, temporal parameters of speech are imperative for achievement of perceptually accurate speech. Furthermore, temporal discoordination has been identified as a core characteristic of AOS (Strand & McNeil, 1996). Temporal features of apraxic speech is consequently often investigated and contrasted with linguistic level deficits.

3.3 THE NATURE OF PHONEMIC OR LITERAL PARAPHASIA: DIFFERENTIATION BETWEEN AOS AND PP

Although AOS is now generally recognized as a phonetic-motoric disorder "it frequently co-occurs with aphasia and differentiating between the respective phonetic-motoric and linguistic impairments has proven difficult" (Ballard *et al.*, 2000:969). The linguistic impairments refer to the phonological errors which have been found to overlap between persons with AOS and those with CA exhibiting a preponderance of PPs (Blumstein, 1981; Kent and McNeil, 1987). The underlying nature of the disorders in persons with AOS and persons with PP is, however, proposed to be at two distinct levels of the speech production process (McNeil *et al.*, 1997; Van der Merwe, 1997). In the past, both these groups of speakers were proposed to exhibit sound substitutions and errors of sequencing (Wertz *et al.*, 1984). This led to persons with PP sometimes being mistakenly diagnosed as exhibiting AOS and vice versa. Currently it is known, however, that the perceived sound substitutions in AOS are in

fact, in many instances, due to distortions caused by prolonged and/or devoiced phonemes (McNeil *et al.*, 1997).

McNeil *et al.* (1997:326) state "the goal of contrasting assumed mechanisms, signs and symptoms between AOS and PP is also to eventually work out the significant characteristics of the groups and find constant differences between them". For this reason, it is necessary to take a closer look at the speech errors of persons with a preponderance of PPs. Persons with aphasia exhibiting a preponderance of PPs will be referred to as speakers with PP. Since PPs often occur in persons with CA, speakers with this type of aphasia are generally included in studies which attempt to investigate the nature of PP.

The speech of persons with PP is characterized by the presence of sound or syllable sequencing errors, which can include perseverative, anticipatory or metathetic errors, as well as sound substitutions. Furthermore, more errors are generally made on consonants than on vowels and these persons are less consistent than subjects with AOS regarding the location of errors on repeated trials of the same utterance. Persons with PP also exhibit greater variability in the type of errors on repeated trials of the same utterance than persons with AOS. They do not exhibit errors of stress or sound distortions and, like AOS, do not have weakness or abnormal reflexes of the speech musculature when used for non-speech activities (Collins, 1989; Goodglass & Kaplan, 1983; McNeil, 1993; McNeil, Odell, Miller & Hunter, 1995).

Explanations for the underlying deficit in persons with PP include a deficit regarding phonological encoding (Friedrich, Glenn & Marin, 1984), phonemic encoding (Brown, 1975), a stage in motor encoding (Yamadori and Ikumura, 1975), pre-articulatory programming (Kohn, 1984), an impaired ability to generate and maintain abstract phonological codes (Friedrich *et al.*, 1984) and a deficit regarding phonological selection and sequencing as a component of linguistic-symbolic planning (Van der Merwe, 1997). The speech errors of persons exhibiting a preponderance of PPs are thus generally proposed to represent a linguistic or phonological impairment, whereas the speech errors of persons with AOS presumably represent a phonetic-motoric impairment (McNeil *et al.*, 1995). Since the level of disruption in AOS and PP is presumably at two distinct levels of the speech

production process, the study of both these disorders in conjunction renders the possibility to contrast the mechanisms involved in error production and to further clarify the nature of AOS.

Studies attempting to differentiate between the speech errors of subjects with AOS and CA exhibiting a preponderance of PPs, have employed examination of factors such as, consistency of error location, variability of error type and successive approximation towards speech targets (McNeil *et al.*, 1995), temporal characteristics of speech production (IAS and durational measures) and the degree of variability regarding temporal measures (Kent and McNeil, 1987; McNeil *et al.*, 1989; Robin *et al.*, 1989; Seddoh *et al.*, 1996a). Although the results of these studies are not all in agreement, the general conclusion has been that AOS is a motor programming disorder as defined in traditional three-level models of speech production (Darley, Aronson & Brown, 1975) or a motor planning disorder, as defined in the four-level framework of speech sensorimotor control by Van der Merwe (1997). AOS is thus viewed as distinct from PP which is ascribed to a deficit regarding phonological planning which is a component of the level of linguistic-symbolic planning as defined in Van der Merwe's (1997) four-level framework.

A complicating factor when attempting differentiation between AOS and PP, is the fact that a motor component has occasionally been proposed to contribute to the pathogenesis in persons with PP, although the nature thereof might be qualitatively different than in AOS (Kent & McNeil, 1987). McNeil, Hashi and Tseng (1991b:1) state that "the traditionally assumed unidimensional phonological-level mechanisms for the speech errors of the conduction aphasic have recently been contested". Features which traditionally have been assigned to AOS, for example, difficulty with initiation of speech and variability of errors, are also shared by persons with PP (McNeil *et al.*, 1997). So, for instance, studies regarding force and position control (McNeil *et al.*, 1990b), absolute and relative timing of speech movements (Kent & McNeil, 1987; McNeil *et al.*, 1990a; Seddoh *et al.*, 1996b), kinematic parameters of movement (McNeil & Adams, 1991), motor control (Clark & Robin, 1998) and token-to-token variability (Kent & McNeil, 1987) have indicated that there might be a motor deficit contributing to the speech deficits in persons with predominant PPs.

The reason for concluding that a motor component is possibly concomitant to the linguistic disorder, stems from the belief that temporal abnormalities "are best interpreted as meaning that motoric planning or execution or both are disrupted" (Kent & McNeil, 1987:213). McNeil *et al.* (1991b:1) state, however, that "an adequate characterization of this phonetic-level deficit has yet to be offered" when referring to the presumed motor deficit in PP.

Regarding the problematic differentiation of the underlying cause of errors in AOS and PP, Blumstein (1981:135) stated:

> In reality, it would not be surprising to find similar patterns of phonological disintegration whether the errors are articulatory or linguistically based, primarily because theoretical linguistic assumptions are derived from the intrinsic nature or organization. Thus, what is articulatorily simple is phonologically or linguistically simple, and what is articulatorily complex is also linguistically complex.

Errors which are measured acoustically could thus presumably be the result of breakdown at either the linguistic or motor planning levels of speech production. In this regard, Rosenbek (2001) proposed that the speech production system might have a limited number of ways to compensate for deficits at any level, with the implication that linguistic-level deficits might be reflected in the temporal parameters of speech production. Rosenbek (2001:269) stated "cognitive, linguistic, and motoric deficits will have a common appearance when motor performance is the outcome measure". In other words, if temporal aspects are measured, the measured parameters might be indicative of a deficit at either the linguistic or motoric level.

Dogil and Mayer (1998) have similarly proposed that temporal deficits evidenced in the acoustic signal might be indicative of higher level phonological impairment and not necessarily of a motor impairment. Kent and McNeil (1987) also speculated about whether phonemic and phonetic-motoric disruptions represent two separate kinds of disruption or rather one common underlying disorder. These researchers proposed that "uncertainties and inefficiencies at a relatively abstract level of speech are reflected in the motor processes that they drive" (Kent & McNeil, 1987:214). In

other words, deficits regarding either phonological or phonetic processes will be manifested as aberrant temporal patterns. As an alternative these researchers propose that the phonological and phonetic-motoric levels of organization might be inseparable and that a division between these two levels is invalid.

Regarding performance on non-speech motor control tasks, persons with CA have not consistently been found to exhibit deficits, unlike persons with AOS (Hageman *et al.*, 1994; McNeil *et al.*, 1990b). The aforementioned finding could be indicative of the fact that the nature of the presumed motor deficit in PP is qualitatively different compared to AOS, if indeed a motor deficit is part of the pathogenesis of PP. Clark and Robin (1998), in a study of non-speech movements in AOS and CA, found that one of their subjects with CA exhibited reduced amplitude parameterization accuracy indicating that motor control deficits might be concomitant to the linguistic disorder in some patients with CA. However, these researchers concluded that a motor control deficit does not appear to be a core part of the underlying disorder in CA.

Since persons with either AOS or PP share certain speech characteristics (Blumstein, 1981; McNeil & Kent, 1990; Odell, McNeil, Rosenbek & Hunter, 1991a, b) with different proposed levels of breakdown, it seems sensible to include both these groups of speakers when examining aspects of speech motor control. Studying the effect of different contextual factors on speech production in these two groups of speakers might further elucidate the nature of these disorders. The results obtained from both these groups of speakers will assist in verifying or refuting traditional views of these two disorders and aid in the shaping of models which have been compiled in an attempt to explain normal and pathological speech motor control. These proposed models, theories and frameworks will be discussed in the following section.

3.4 THEORIES REGARDING THE UNDERLYING NATURE OF APRAXIA OF SPEECH

The proposed definitions of AOS attempt to highlight the essence of the disorder and its primary characteristics. In an attempt to elucidate the underlying nature of the disorder, responsible for the perceived characteristics, several theories, models and

frameworks for characterization of AOS have been compiled. In this regard, Miller (2002:225) stated "viewing AOS in the context of overall models of motor speech production may lay out a more fruitful and systematic line of enquiry in the quest for understanding how speech is controlled, how it breaks down, and what the underlying nature of this disorder might be". Theories for explanation of the underlying deficit in AOS will be reviewed in the following section. Where applicable, reference will be made to the contribution these theories make in explaining the nature of PP and the role of contextual factors in speech production.

Despite the now general consensus that AOS is a phonetic-motoric disorder, different theories attempting to provide explanations for the source of errors and the underlying nature of the disorder have been proposed (for example, Dogil & Mayer, 1998; Kelso and Tuller, 1981; Mlcoch and Noll, 1980; Rogers and Storkel, 1999; Van der Merwe, 1997; Whiteside and Varley, 1998). According to Ballard *et al.* (2000:970) "the prevailing theoretical approach to AOS claims that the processes that build the phonological representation of a message are intact but the phonetic-motoric level of production is disrupted". Each of the proposed theories for the explanation of the underlying nature of specifically AOS will now be reviewed in more detail.

3.4.1 Van der Merwe's four-level framework for the sensorimotor control of speech

The framework proposed by Van der Merwe (1997) was discussed in depth in chapter two. The fact that Van der Merwe (1997) differentiates between four different phases or levels in the speech production process implies that distinct disorders can arise due to deficits at any one of these four levels. According to Van der Merwe (1997), reconsideration of neurogenic communication disorders within the context of this framework is needed, since traditional models only distinguished three levels in the speech production process (Van der Merwe, 1997). She postulates, however, that due to the fact that some neural structures are involved at several levels of control, a specific disorder might exhibit deviances at more than one level of the proposed framework. This might explain the presumed motor component which is occasionally reported in persons with PP.

Van der Merwe (1997) postulates that a deficit at the level of linguistic-symbolic planning will result in speech and language errors, which are characteristic of persons with aphasia. The latter includes aspects, such as, difficulty with semantic, lexical, morphological and phonological planning. Difficulties with phonological planning will result in problems with the selection and sequencing of phonemes which in turn could lead to substitutions and transpositions. Phonological paraphasias, often predominant in persons with CA, would be characteristic of a deficit at this level of the speech production process.

Within this framework, persons with AOS, who exhibit distortions as a core feature in their speech (Itoh & Sasanuma, 1984), display a deficit regarding the motor planning of speech. Van der Merwe (1997:17) proposes that a deficit regarding the motor planning of speech can involve aspects, such as, difficulty or inability to recall invariant core motor plans for specific phonemes, difficulty identifying different motor goals for specific phonemes, sequencing the movements for each phoneme or sequential movements for a phoneme sequence, adaptation of the spatial and temporal features of the core motor plan to the phonetic context, control of IAS, central monitoring of the efference copy, keeping movement and adaptation within the boundaries of motor equivalence and difficulty relaying the structure-specific motor plan subroutines to the motor programming system. Difficulty with any of these functions would presumably result in slow effortful speech with frequent distortions and even substitutions as is evident in persons with AOS (Van der Merwe, 1997).

As discussed in chapter two, Van der Merwe (1997) depicts speech production as being context-sensitive and emphasizes that fact that some contexts of speech production might require more complex control strategies than others. She mentions the fact that apraxic speech symptoms have been found to vary depending on the context of production and consequently underscores the need to study the influence of various contextual factors on the different levels of the speech production process.

3.4.2 Kelso and Tuller's (1981) coalitional theory of AOS (dynamic pattern theory)

Kelso and Tuller (1981) apply their coalition model to AOS and propose that AOS occurs due to "breakdown in the synergistic relationship between the individual and the environment" (Kelso and Tuller, 1981:233). This breakdown results in failure to meet behavioral goals which, in the case of speech production, entail accomplishment of spatiotemporal goals for intra- and interarticulatory synchronization. According to proponents of this theory the invariant features of movement are represented as attractor states (Ballard, Barlow & Robin, 2001). According to Ballard *et al.* (2000, 2001) attractor states are action patterns which emerge through a combination of factors, including the interaction of the parts of a system with each other and with the external environment, the inherent constraints on the system and the supply of energy which is available. During every performance in varying contexts, the pattern emerges as a new form, although some features remain stable and predictable. When a specific pattern reoccurs consistently, the stability of the emergent pattern increases and develops into an attractor state. The system is able to adapt and reorganize in response to new contexts and conditions (Ballard *et al.*, 2001).

When the motor system is impaired, for example in the case of AOS, the stability of the attractor states is disturbed and the patterns are consequently disrupted or lost. Ballard *et al.* (2001:54) state that this theory "might predict that AOS represents damage to the machinery (i.e. neural substrate) that constructs emergent patterns". The speech of persons with AOS thus represents instability, implying an impaired ability to reach former attractor states (Ballard *et al.*, 2001). Increased token-to-token variability regarding durational parameters, which has been reported for persons with AOS (Kent & McNeil, 1987; Seddoh *et al.*, 1996a, b; Strand & McNeil, 1996), might be indicative of the instability of their speech motor systems. Furthermore, distortions, indicative of temporal and spatial disruptions, might be reflective of the inability of the speech motor systems of persons with AOS to reach these former stable attractor states.

Evidence for the disrupted timing of the tight temporal coupling of the articulators in AOS comes from studies on IAS. From the results of studies investigating, for example, velar movements in an apraxic speaker (Itoh, Sasanuma & Ushijima, 1979b) and articulatory movements of the tongue, lips and velum (Itoh, Sasanuma, Hirose, Yoshioka & Ushijima, 1980), Kelso and Tuller (1981) deduced that the timing patterns between the various articulators might be disrupted in persons with AOS. Studies reporting deficits regarding VOT in AOS (Freeman *et al.*, 1978; Lisker & Abramson, 1964; Sands, Freeman & Harris, 1978) have also been taken as evidence for "disruption of the normally invariant timing relations among articulators" (Kelso & Tuller, 1981:241).

Although Kelso and Tuller (1981) emphasize the importance of the context for motor learning, they do not elaborate on contexts for speech production and postulate that constant relative timing should be preserved regardless of the context of an utterance. Kelso and Tuller's (1981) proposed style of motor organization thus predicts constant timing relations between the articulators despite changes in the external context inducing increased processing demands, for example, when having to increase speaking rate. They postulate that relative timing of neuromuscular events between muscles remains constant even though the absolute timing and spatial parameters of the movements varies. This model does not explain speech errors such as PPs and only emphasizes the control of movement itself. Dynamic systems theory does not explicitly say how language operates within the motor system, nor does it predict how different contextual factors would impact on motor performance, apart from the fact that relative timing would be preserved in such situations.

3.4.3 Theories incorporating concepts of attentional resource allocation or resource capacity limitations

Several theories incorporating the concepts of attention, resource allocation and resource capacity limitations have been proposed to explain the nature of the deficit in AOS (Clark and Robin, 1998; Kent and McNeil, 1987; Rogers and Storkel, 1999; Whiteside and Varley, 1998) and aphasia (Kent & McNeil, 1987; McNeil *et al.*,

1991a; Tseng, McNeil & Milenkovic, 1993). The nature of these theories will be reviewed in the following section.

3.4.3.1 A resource allocation deficit

Kent and McNeil (1987) posed that explanation for the token-to-token variability in the subjects with AOS and CA in their study, needed to incorporate the concept of a resource allocation deficit. According to these researchers, information on syllable structure and phoneme segments is coded separately with the consequence that these two aspects can be differentially affected. Since AOS and CA subjects in their study were prone to deficits at the phonetic-motor planning level, Kent and McNeil (1987) speculated that more attention/resources might be allocated to "the slot-filler specifications of individual syllables and their motoric realization" (Kent & McNeil, 1987:213). According to these researchers, the increased resource allocation to slot-filler specification and motoric realization of individual syllables, as opposed to larger units, might result in the lengthening of both syllables and intersyllabic pauses, causing the secondary characteristic of dysprosody. The latter result was more pronounced for the subjects with AOS in their study.

McNeil *et al.* (1991a) have also proposed a deficit regarding the allocation of attention as explanation for performance variability from one situation to another on the same task in aphasic speakers. These researchers argued that researchers had "failed to provide the necessary and convincing evidence that the linguistic data and the computational linguistic operations are lost", since aphasics can execute certain tasks successfully in certain environments, for example, when counting or naming the days of the week (McNeil *et al.*, 1991a:35). They conclude that the current linguistic models alone can thus not adequately explain aphasia. For this reason, concepts of attention and memory need to be incorporated into the explanation of the underlying pathology in this population (McNeil *et al.*, 1991a). Persons with aphasia thus presumably still have the underlying linguistic competence, but linguistic performance is influenced by difficulty with adequate allocation of resources to the linguistic task at hand (McNeil *et al.*, 1991a). The use of an attention framework for aphasia allows explanation of aspects, such as, variability, stimulability and multidomain deficits in aphasic speech performance. These aspects of aphasic

behavior cannot be accounted for by traditional explanations of the underlying disorder (McNeil *et al.*, 1991a; Tseng *et al.*, 1993).

If persons with AOS and CA have difficulty with the allocation of resources, contexts which challenge the speech production mechanism and require allocation of more attention might cause breakdown in the speech production process of these persons, since more resources than normal already need to be allocated to the defective speech and language processes. A person with a normal neuromotor system would presumably be able to adapt successfully to more challenging contexts and successfully allocate additional resources where needed. Contexts which are more challenging would presumably require more conscious processing and consequently allocation of more attentional resources (McNeil *et al.*, 1991a). McNeil *et al.* (1991a) underscore the fact that the processing of a more complex task requires greater resources and controlled processing, whereas automatic tasks impose a small processing load and consequently require fewer resources and less attention for execution.

From the above discussion, it is evident that contextual demands play an integral part in the performance of both persons with AOS and aphasia. The influence of various contextual factors will consequently need to be taken into account when compiling evaluation and treatment methods. Depending on the underlying nature of the disorder, different contexts might affect speech production in a specific population differently. It is thus important to determine the effect of various contextual factors in different disorder groups, not only for incorporation of this knowledge in assessment and treatment, but also for learning more about the underlying nature of these disorders.

3.4.3.2 Whiteside and Varley's (1998) dual-route hypothesis for phonetic encoding

Whiteside and Varley (1998) offer a cognitive-based conceptualization of AOS. These researchers propose that normal speech production occurs by means of access to either a direct or indirect processing route. The direct route accesses stored verbo-motor patterns or whole gestalts (Varley & Whiteside, 2001). These verbo-motor

patterns contain the specifications for the relative timing and force for movements of the components of coordinative structures. The movement parameters of frequently used syllables and words are stored and can be accessed via the direct route. Whiteside and Varley (1998:223) state that "In order to reduce computational complexity and therefore the degrees of freedom, the physiological system will link variables to form self-regulating autonomous subsystems" as also proposed by Kelso and Tuller (1981). Speech production is thus simplified through the use of "learned links between muscle commands" (Whiteside and Varley, 1998:223). The result is generation of programs of movement synergies or verbo-motor patterns. Because this route is used for retrieving frequently used utterances, minimal computational resources are required and direct access is offered to a hypothetical mental store of "phonetic"/"mental syllabary" (Levelt, 1989, 1992).

The indirect route, on the other hand, is used to assemble low frequency or novel utterances and these utterances have to be assembled anew each time phone by phone. Consequently this route imposes an increased processing load and individuals with brain damage are known to exhibit difficulty with allocation of attentional resources (Ballard *et al.*, 2001). Whiteside and Varley (1998) propose that persons with AOS exhibit a deficit regarding either the access to and/or the storage of verbo-motor patterns. Consequently the person with AOS has to rely on the indirect encoding route and assemble utterances anew each time, phone by phone. From the speech characteristics of persons with AOS, these researchers concluded that these persons cannot efficiently and adequately compensate through the use of indirect mechanisms though.

Whiteside and Varley (1998) claim that apraxic speech characteristics, such as, reduced coarticulation (McNeil, Hashi & Southwood, 1994; Ziegler & von Cramon, 1985), articulatory groping (Darley *et al.*, 1975), increased segmental and intersegmental duration (Freeman *et al.*, 1978; Kent & Rosenbek, 1983; Mercaitis, 1983; Strand & McNeil, 1996), variable and inconsistent VOT patterns (Freeman *et al.*, 1978; Itoh *et al.*, 1982; Kent & Rosenbek, 1983; Whiteside & Varley, 1996; Ziegler, 1987) and interarticulatory dyscoordination (Freeman *et al.*, 1978; Itoh *et al.*, 1979a, b; Kent & Rosenbek, 1983; Ziegler and von Cramon, 1986) can be accounted for by inefficiency of the indirect route used in isolation. An alternative explanation

they provide is that concomitant deficits regarding allocation of processing resources negatively affect the abilities of persons with AOS to make use of the indirect route efficiently, since this route relies heavily on on-line computation and controlled processing. Varley *et al*. (1999:128) contend that the increased processing demands might be "problematic for a speaker with a lesion in the motor control regions of the dominant hemisphere".

The proposal by Whiteside and Varley (1998) has been criticized by researchers on several accounts (Ballard *et al.*, 2001; Miller, 2001; Ziegler, 2001). Ballard *et al.* (2001) criticized the dual-route model on various grounds including, the fact that apraxic speech behavior could be explained by other theories equally well and that support for units smaller than a word has been found in the linguistic literature (Rogers & Spencer, 2001). Ballard *et al.* (2001) further stated that it would be difficult to falsify or even test the model of Whiteside and Varley (1998) and that their model could not account for non-speech findings in AOS, which have been reported by, for example, Clark and Robin (1998). Miller (2001) also criticized the dual-route model by stating that the results of their study do not necessarily imply a "contrast between utilizing prestored versus planned-afresh gestalts" (Miller, 2001:64). According to Miller (2001) durational differences which Varley *et al.* (1999) reported for high and low frequency words, could possibly arise from functionally different performance within a single route. Miller (2001) also criticized Whiteside and Varley (1998) regarding subject selection criteria, implying that the degree of concomitant aphasia and dysarthria in their AOS subjects could have influenced their results.

Regarding Whiteside and Varley 's (1998) dual-route hypothesis, Rogers and Spencer (2001) raised the question as to why automatic speech utterances of speakers with AOS are nearly invariably better than any other types of speech, if direct route encoding is indeed impaired. Ziegler (2001) pointed out the fact that normal speakers only have minor, if any, problems when attempting to produce words which they have never heard before and if speakers with AOS were using the indirect route for compilation of utterances, their speech should be on par with that of normal speakers producing new or unfamiliar utterances. This is not the case, however, since the speech of persons with AOS is characterized by severe sound distortions and

substitutions, together with struggle behavior, none of which are evident in normal speakers producing novel words (Ziegler, 2001).

The direct route can be seen as the automatic route of speech production and the patterns which can be accessed via this route are thus highly familiar and overlearned. The indirect route, on the other hand, contains access to novel and unfamiliar responses. Consequently, these two routes can be regarded as two separate contexts for speech production. Familiar utterances utilizing the direct route are more automatic and require fewer attentional resources, whereas the indirect route requires more conscious processing since these words are novel and less automatized. In this sense, novel words present a different and more demanding speech context than high frequency words which are presumably more automatized and overlearned.

As argued by Ballard *et al.* (2001), the proposals by Whiteside and Varley (1998) can be explained by other theories of normal and pathological speech motor control equally well. For example, Van der Merwe's (1997) four-level framework of speech sensorimotor control also predicts that novel utterances might increase the processing load, since the motor plans are not as well established as those of utterances which are more familiar and automatized. Since speech is a motor skill, it improves with practice and becomes more automatized with the result that utterances which are used more frequently will be produced with greater ease and speed if language processes are intact. Varley *et al.* (1999) explain AOS from a cognitive perspective, whereas explanation from a motor control perspective has potential to explain the occurrence of a wider range of speech characteristics in normal and pathological speakers.

3.4.3.3 Rogers and Storkel's reduced buffer capacity hypothesis in AOS

Rogers and Storkel (1999) postulated a reduced capacity of the sublexical processing buffer in AOS. According to these researchers, this capacity problem results in one of the core feature of AOS, namely, syllable segregation. The reason for syllable segregation is presumably that persons with AOS can only plan one syllable at a time (McNeil, Doyle & Wambaugh, 2000).

Initially Rogers and Storkel (1998) conducted a series of five experiments to determine the role of articulatory phonetic features (voicing, place and manner of articulation) and reprogramming operations during the pre-motor stages of speech production. Speech onset latencies were obtained from normal speakers who had to read monosyllabic words presented one at a time as quickly as possible after they appeared on a computer screen. Latencies of words which were preceded by words sharing their phonetic features were contrasted to control conditions in which there were no shared features between consecutively presented words. A *phonologic similarity effect* was found, meaning that consecutively presented words, which shared features regarding the initial sound, rendered significantly longer onset latencies than words of which the initial sounds did not share articulatory phonetic features. The latter finding was taken as evidence for the idea that sublexical units have to be assembled (Rogers & Storkel, 1998) and longer latencies presumably provided evidence of the processing which was required to reprogram the pre-motor processing buffer (Rogers & Spencer, 2001). The researchers ascribed the additional processing time which was required for production of words of which the initial phonemes shared articulatory features, to temporary inactivation of programs which had been used for production of the initial word.

Rogers and Storkel (1999) conducted another experiment involving a parameter re-mapping task where speakers were presented simultaneously with two words sharing articulatory phonetic features, in order to provide them with time to plan/program the utterance before production onset. The need to reprogram the processing buffer between the first and second word was thus alleviated by simultaneous presentation of both words. Rogers and Storkel (1999) predicted that the phonological similarity effect would disappear in normal speakers when both words were presented simultaneously, since these speakers now did not have to reprogram the phonological buffer for the following word, but could plan production of both utterances. Rogers and Storkel (1999) hypothesized that if subjects with AOS exhibited a reduced phonological buffer capacity, the phonological similarity effect would still be present in these persons, despite both words being presented simultaneously, since they would still need to program each word independently.

In the abovementioned experiment by Rogers and Storkel (1999), subjects were thus required to plan production of two words at a time. Slowed production was taken as proof that two words could not be held in the phonological buffer for planning at one time. The initial phonemes of the two words shared one of the following groups of features, namely, voicing and manner of production, place and manner of production, or no similar features. Two measures of inter-word interval duration were obtained. Normal speakers and persons with either aphasia or aphasia with concomitant AOS, served as subjects in this study.

The results of the second study by Rogers and Storkel (1999) revealed that only the AOS subjects exhibited the phonological similarity effect, in other words, exhibited increased latencies for production of words of which the initial phonemes share articulatory features. The latter finding confirmed that the subjects with AOS exhibited a reduced phonological buffer capacity preventing the programming of both words simultaneously. Ballard *et al.* (2000) state that in agreement with the explanation by Rogers and Storkel (1999), other researchers, for example, Rochon, Caplan and Waters (1990) have proposed a reduced short term memory in speakers with AOS resulting from "a reduced ability to perform articulatory rehearsal" (Ballard *et al.*, 2000:974).

From the reduced buffer capacity hypothesis for explanation of articulatory prolongation and syllable segregation in AOS, it can be concluded that the length of an utterance can be seen as a context for speech production. In this regard, longer utterances presumably pose higher demands regarding phonological and motor planning. Persons with AOS are thus more prone to experience difficulty with longer utterances and are more susceptible to breakdown regarding longer utterances (Johns & Darley, 1970; Shankweiler & Harris, 1966; Strand & McNeil, 1996) due to their reduced capacity to plan production of more than one syllable at a time. The theory proposed by Rogers and Storkel (1999) does not allow for explanation of other apraxic speech characteristics, for example, the presence of distortions. Furthermore, the theory by Rogers and Storkel (1999) does not predict the influence of other contextual factors, for example, speaking rate.

The finding that persons with AOS consistently had difficulty planning two utterances when features were shared between the initial sounds of two words which had to be produced consecutively (phonological similarity effect), could also be attributed to the fact that the production of longer utterances are more difficult for persons with AOS, since they are motorically more complex (Van der Merwe, 1997, 2002). Van der Merwe (2002) states that the number of core motor plans which need to be recalled is greater, sequential organization of motor goals is more demanding, the potential for coarticulation increases and IAS also becomes more complex in longer utterances. The phonological similarity effect, reported by Rogers and Storkel (1999) might thus be related to difficulty with the processes occurring during the motor planning of speech and not only to a reduced phonological buffer capacity. Rogers and Storkel (1999) do mention, however, that although their experiment was designed to affect phonological encoding, processing at the subsequent stages, for example, motor programming, might also have been affected. Phonological similarity of utterances can also be regarded as a contextual factor influencing the processing demands.

3.4.4 Selective phonological impairment

Dogil and Mayer (1998) offer a linguistic-based account for AOS. These researchers propose that AOS reflects a purely linguistic or phonological impairment. Dogil and Mayer (1998) performed a cross-linguistic study with German-speaking and Xhosa-speaking persons with AOS and concluded that AOS reflects a "defective implementation of phonological representations at the phonology-phonetics interface" (Dogil & Mayer, 1998:143). Underlying their conclusion is their belief that "speech is encoded in the brain as a sequence of distinctive feature configurations" (Dogil & Mayer, 1998:143). According to these researchers, these configurations are specified with varying degrees of detail depending on their role in the phonological structure of the language. Dogil and Mayer (1998) propose that speech sounds are encoded as a sequence of vocal tract configurations when the transfer from phonological to phonetic representations occurs.

The deficits characteristic of AOS are explained in terms of over-specification of these articulatory configurations, thus over-specification of sounds at the phonetic

level, resulting in the inability to coarticulate sounds. In normal speakers a considerable amount of phonological under-specification and phonetic non-specification occurs to accomplish fluently articulated speech. According to these researchers, a speaker with AOS exhibits a "loss of the ability to construct underspecified representations" (Dogil and Mayer, 1998:152) which are subject to coarticulatory effects. These researchers verify this claim by stating that coarticulation in AOS is greatly limited, production of underspecified speech sounds (laryngeal and schwa-like vowels) is difficult and specified speech sounds, like clicks in Xhosa, are produced correctly by persons with AOS, even though these sounds are motorically complex sounds (Dogil & Mayer, 1998). These observations led Dogil and Mayer (1998) to conclude that the underlying problem in AOS is phonologically based as opposed to motor-based. Dogil and Mayer (1998:168) argued that their over-specification hypothesis suggests that gestural complexity does not play a role, but rather "the degree of phonological (under) specification and the ability to preserve it at the phonetic level".

Ballard *et al.* (2000) state that Dogil and Mayer's (1998) account of AOS cannot explain the nonspeech motoric impairments observed by other researchers, for example, Clark and Robin (1998). The fact that the subject studied by Dogil and Mayer (1998) produced click sounds correctly could indicate that more conscious processing was employed during production of this sound, since it is motorically complex and perceptually distinct. Furthermore, this particular sound occurs very frequently used in Xhosa and production thereof could consequently be more automatized than the more neutral sounds, even though it is motorically complex.

The fact that it is generally reported that persons with AOS exhibit greater difficulty with sounds and sound combinations which are motorically more complex (Van der Merwe, 1986) is contradictory to the explanation provided by Dogil and Mayer (1998) for the correct production of the motorically complex click sound. Different contextual factors, for example, level of automaticity (Van der Merwe, 2002), frequency of use of the sound in a particular language (Trost & Canter, 1974) or length of the utterance (Johns & Darley, 1970; Shankweiler & Harris, 1966; Strand & McNeil, 1996) in which the sound occurs, could also contribute to accuracy of production. Difficulty or success with the production of a specific sound can thus not

be solely attributed to the distinctive features of which the sound is comprised, but other contextual factors need to be considered as well. The reduced coarticulation in speakers with AOS can be explained equally well by motor-based accounts. The lack of coarticulation could be reflective of an inability to adapt the temporal and spatial parameters of speech production to the phonetic environment during the motor planning stage of speech production (Van der Merwe, 1997). From the latter perspective difficulty regarding the motor planning of speech is present in subjects with AOS.

3.4.5 Schmidt's schema theory

According to Schmidt's schema theory, learned movement patterns are stored as generalized motor programs (GMPs). These GMPs could include articulatory gestures, segments, syllables, words or even high-frequency phrases (Ballard *et al.*, 2001). Depending on the context in which a movement is produced, parameters are adapted regarding the absolute force and duration of the movements. The same utterance will thus differ regarding the absolute temporal and spatial parameters depending on the context of production, as well as during repeated production of the same utterance. The concept of GMPs and parameterization, reduce the storage demands for action representations and account for the relatively invariant features across different productions of an action (Schmidt, 1975). It is not certain what would be regarded as "contexts" for speech production in Schmidt's (1975, 1982) view, but it would most probably entail the phonetic environment or different circumstances under which speech is produced, for example, different speech rates. The context as proposed by Schmidt (1975) could also possibly refer to the same utterance produced at different times or during repeated productions.

Clark and Robin (1998) conducted a study, against the backdrop of Schmidt's theory, in which they examined motor programming in normal speakers, persons with AOS and persons with CA by means of a visual-motor tracking task. The aspects they examined included, GMP accuracy, as well as temporal and spatial parameterization accuracy. Subjects had to produce a movement pattern presented on a monitor with their jaw, after the pattern had been removed from view. The results of the study

indicated inter-subject variability in the AOS group in that two of the four subjects demonstrated unimpaired GMP accuracy, but poor parameterization accuracy, while the other two subjects displayed impaired GMP accuracy with normal parameterization.

Clark and Robin (1998) concluded that their results indicated the presence of possible performance trade-offs, since the subjects with AOS in their study had deficits regarding either the GMP or parameterization, but not both. They explained this finding by stating that subjects might have only enough processing resources to correctly program either the GMP or the parameters, but not both. According to these researchers, the inter-subject variability might thus be indicative of different resource allocation strategies used by the different subjects with AOS. Because of their impaired motor system, subjects with AOS might reach the limits of their capacity, forcing them to choose one of these aspects of motor programming to attend to, since their resources are too limited to attend to both (Clark & Robin, 1998). Clark and Robin (1998:710) concluded that AOS involves the entire process of motor programming as opposed to involvement of "only one process (the GMP) within the programming of events". Furthermore, these researchers stated that speakers with AOS are thus required to produce skilled movement "under great resource demand, resulting in an increased susceptibility to breakdown" (Clark & Robin, 1998:710). In terms of Schmidt's schema theory, AOS can thus be thought of as a deficit regarding the ability to activate and/or select a GMP, an inability to correctly parameterize according to a given context, or both (Clark & Robin, 1998).

Clark and Robin (1998) also included subjects with CA in their study. These researchers found that with the exception of one subject, the subjects with CA did not generally exhibit difficulty with implementation of GMPs or parameterization accuracy. From this result, these researchers concluded that some patients with CA might have motor control deficits concomitant to a primary linguistic disorder, but that difficulty regarding motor control is not a core part of the pathogenesis in CA.

As in Van der Merwe's (1997) four-level framework of speech sensorimotor control, Schmidt's theory also proposes that the parameters (spatial and temporal) of movement vary according to the context, although he does not specify specific

contexts for speech production. Furthermore, the influence of contextual factors regarding the demands which they place on the speech production mechanism is not commented on. It is assumed, however, that implementation of correct GMPs and/or parameterization accuracy will be influenced by contextual factors which increase the processing demands to the speech production mechanism.

3.4.6 Conclusion regarding theories about the underlying nature of AOS

From the above discussion, it is evident that different explanations exist for the underlying nature of AOS and PP. Each theory presents specific strengths and weaknesses to aid in our understanding of AOS and other neurogenic speech and language disorders. From these theories, it becomes evident that the influence of contextual factors need to be incorporated in models and theories of disordered speech, since speech production is variable due to the influence of contextual demands. Before discussing specific contextual influences on the speech of persons with neurogenic speech and language disorders, temporal aspects of speech production which are studied in an attempt to learn more about the underlying nature of the disorders in these persons will be reviewed. Perceptually on-target speech production will require accurate specification of the spatial and temporal parameters of speech production. The study of these parameters serves as a window through which one can catch a glimpse of the underlying processes involved in speech production.

3.5 THE STUDY OF TEMPORAL PARAMETERS OF SPEECH PRODUCTION IN AOS AND CA: A WAY IN WHICH TO INVESTIGATE THE NATURE OF THE DISORDER

Speech timing has been of considerable interest to researchers concerned with speech disorders due to neurologic etiologies. The main reason for this interest is because deviant articulatory timing resulting in articulatory deficits can be used to characterize the underlying impairment, for example, motor versus phonological impairment, in such disorders and consequently for differentiation of the nature of these disorders

(Ballard *et al.*, 2000). In this regard, Ballard *et al.* (2000) state that the examination of temporal characteristics of speech production is helpful for characterizing deficits in speech and/or language disorders as being either motoric or linguistic in nature.

Studying speech timing in pathological speakers also renders important information that can be used when compiling and verifying aspects of models of normal and pathological speech motor control. Temporal aspects of speech production have been widely studied in AOS, due to the fact that these subjects are believed to exhibit deficits regarding temporal control (Seddoh *et al.*, 1996b; Strand & McNeil, 1996). Inclusion of subjects with CA in such studies is valuable for determination of qualitative differences regarding temporal control and for differential diagnostic purposes, since persons with either AOS or PP are believed to exhibit deficits at two distinct levels of the speech production process.

Various acoustic (Freeman *et al.*, 1978; Itoh *et al.*, 1982; Kent & McNeil, 1987; Kent and Rosenbek, 1983; McNeil *et al.*, 1990a; Seddoh *et al.*, 1996a, b; Strand & McNeil, 1996; Tuller & Story, 1987; Ziegler & von Cramon, 1985, 1986), kinematic (Fromm, 1981; Hardcastle *et al.*, 1985; Itoh *et al.*, 1980; McNeil & Adams, 1991; McNeil *et al.*, 1989; Robin *et al.*, 1989; Tseng *et al.*, 1990) and physiologic (electromyographic) (Forrest *et al.*, 1991; Fromm *et al.*, 1982; Shankweiler *et al.*, 1968) studies have been performed in an attempt to determine the temporal characteristics of neurogenic speech disorders and consequently to shed light on the underlying nature of these disorders. By using these techniques interarticulatory timing between various articulators (Itoh *et al.*, 1980; Robin *et al.*, 1989; Tseng *et al.*, 1990), as well as durational aspects of speech timing (Baum, Blumstein, Naeser & Palumbo, 1990; Code & Ball, 1982; Collins *et al.*, 1983; Colson, Luschei & Jordan, 1986; Cooper, Soares, Nicol, Michelow & Goloskie, 1984; Danly & Shapiro, 1982; DiSimoni & Darley, 1977; Duffy & Gawle, 1984; Gandour & Dardarananda, 1984; Harmes, Daniloff, Hoffman, Lewis, Kramer & Absher, 1984; Kent & McNeil, 1987; Kent & Rosenbek, 1983; McNeil *et al.*, 1990a, Ryalls, 1981, 1982, 1986; Square-Storer & Apeldoorn, 1991; Strand & McNeil, 1987; Sussman, Marquardt, Hutchinson & MacNeilage, 1986; Ziegler & Hoole, 1989; Ziegler & von Cramon, 1985) have been studied.

The following section will provide an overview of studies which have examined temporal aspects of speech production in persons with AOS and those with PP. The emphasis will be on acoustic studies of IAS and the duration of speech segments, since these two aspects are the focus of the present study. It is important to study segment durations due to the fact that "they are thought to reflect principles of speech timing" (Forrest & Weismer, 1997). Furthermore, IAS is an important aspect of speech motor control, since it needs to be planned for each phoneme in an utterance (Van der Merwe, 1997). Interarticulatory synchronization is thus reflective of temporal control amongst various articulators, which in turn is essential for achievement of perceptually accurate speech. Durational aspects have been widely studied in persons with neurogenic speech disorders probably due to the perceptual prominence and their importance for differential diagnosis (Strand & McNeil, 1996).

3.5.1 Interarticulatory timing

An aspect of articulatory timing which is often studied in persons with neurogenic speech disorders is the timing of articulatory movements relative to one another, known as IAS or interarticulatory timing. The movements of the different articulators need to be synchronized in order to obtain the desired acoustic result (Itoh & Sasanuma, 1984; Itoh *et al.*, 1980; Kelso *et al.*, 1983.) Interarticulatory synchronization has been studied by means of both kinematic (Fromm, 1981; Hardcastle *et al.*, 1985; Itoh *et al.*, 1980, 1980; Robin *et al.*, 1989; Tseng *et al.*, 1990) and acoustic (Freeman *et al.*, 1978, Itoh *et al.*, 1982; Kent & Rosenbek, 1983; Tuller & Story, 1987; Ziegler & von Cramon, 1985, 1986) measures. In this way IAS in AOS between various articulatory structures has been examined, for example, IAS of the lip, velum and tongue dorsum (Itoh & Sasanuma, 1984; Itoh *et al.*, 1980) and IAS of velar and tongue movements (Itoh *et al.*, 1979b). As mentioned in chapter two, VOT has often been measured in studies on IAS as an indicator of interarticulatory timing, since it reflects the relative timing between a supralaryngeal (oral articulation) and laryngeal event (vocal fold vibration for voicing onset) (Van der Merwe, 1986). Deficits regarding VOT in AOS and CA have consequently been attributed to difficulty regarding temporal control (Kent & McNeil, 1987).

- **Interarticulatory timing of laryngeal and supralaryngeal events in neurogenic speech disorders: voice onset time**

Deviant VOT in AOS has been reported by several researchers (Blumstein, Cooper, Goodglass, Statlender & Gottlieb, 1980; Blumstein, Cooper, Zurif & Caramazza, 1977; Hoit-Dalgaard, Murry & Kopp, 1983; Itoh *et al.*, 1982; Shewan, Leeper & Booth, 1984; Seddoh *et al.*, 1996b) and this consequently implies deviant interarticulatory timing in this population. Deficits regarding VOT include a restricted range of VOT values in some subjects (Hoit-Dalgaard *et al.*, 1983), longer than normal VOT values (Kent & McNeil, 1987), overlapping VOT values for voiced and voiceless cognates (Blumstein *et al.*, 1977; Itoh *et al.*, 1982) and greater variability regarding VOT (Kent & McNeil, 1987). In AOS it seems possible to attribute errors regarding VOT to the presence of a motor disorder manifested, in amongst other characteristics, the disrupted timing of laryngeal and supra-laryngeal events.

In the framework proposed by Van der Merwe (1997) a deficit regarding VOT is ascribed to the level of the motor planning of speech, since the temporal parameters of speech production are specified at this level of the speech production process. Deviant VOT supports the claim of Kelso and Tuller (1981:241) that "apraxia of speech may be characterized, at least in part, by disruption, of the normally invariant timing relations among articulators". Itoh *et al.* (1982:209) also concluded that "the pathological distributions of VOT values shown by the apraxic subjects studied are indicative of the existence of a difficulty in the temporal programming of the laryngeal and supralaryngeal articulatory adjustments rather than a problem in selecting appropriate phonemes". This statement has to be interpreted with reference to a three-level model of speech production as proposed by Itoh and Sasanuma (1984). The term motor programming as used in the three-level model is synonymous to motor planning as used by Van der Merwe (1997) in her four-level framework of speech sensorimotor control. As mentioned previously, motor planning and motor programming are proposed by Van der Merwe (1997) to be two distinct stages in the speech production process. Some researchers have, however, reported normal VOT values in some persons with AOS (Collins *et al.*, 1983; Kent & Rosenbek, 1983;

Shewan *et al.*, 1984; Van der Merwe, 1986), indicating that this aspect of articulatory timing is not necessarily consistently disrupted in AOS.

Regarding VOT measures in CA mixed results have also been obtained in that some researchers have reported normal VOT values for CA (Blumstein *et al.*, 1980; Itoh *et al.*, 1982; Seddoh *et al.*, 1996b; Shewan *et al.*, 1984;), while others have reported aberrant VOT characteristics in some of these speakers (Kent & McNeil, 1987). Intrasubject differences have also been reported in CA. For example, in an acoustic study performed by Kent & McNeil (1987), one of the subjects with CA had VOT values similar to those of the subjects with AOS, while the other exhibited short VOT values.

3.5.2 Duration of speech segments

Stress and durational patterns have been acoustically analyzed more often than other characteristics of apraxic speech due to their importance for differential diagnosis and their perceptual prominence (Strand & McNeil, 1996). Many studies have confirmed the existence of slower rate and abnormal prosodic patterns for apraxic speakers compared to normal or aphasic speakers (Kent & McNeil, 1987; McNeil *et al.*, 1990a; Odell *et al.*, 1991a, b). The source of the slowed speaking rate in AOS has been ascribed to "motoric limitations, compensation for motoric difficulties, or an attempt to reinstall effective self-monitoring" (Kent & McNeil, 1987:214). Kent and McNeil (1987) proposed that speaking rate can be slowed by either lengthening of intersyllabic pauses or lengthening of the segments produced. The study of durational patterns of speech segments in AOS includes the study of vowel duration, consonant duration and word or intersegment durations. Once again, many of these studies included persons with CA in order to contrast the findings and pathological mechanisms in these two groups of speakers.

3.5.2.1 Vowel duration

It has become increasingly evident that vowel characteristics contribute to speech intelligibility deficits to a great extent and that consonants are not the most

"informative bearing" elements of speech (Forrest & Weismer, 1997). Increased vowel durations could thus presumably contribute to the perceived slow rate in AOS, as well as to abnormal prosody (Harris & Umeda, 1974; Umeda, 1974). However, results from various studies regarding vowel duration in AOS and CA have been inconsistent. Some researchers have reported vowel durations within the range of those of normal speakers for both AOS and aphasic speakers for monosyllabic words (Bauman, 1978; Duffy & Gawle, 1984; Gandour & Dardarananda, 1984; Mercaitis, 1983; Ryalls, 1984, 1986). However, other researchers, examining multisyllabic words, have found longer vowel durations in AOS compared to normal speakers and aphasic subjects (Baum *et al.*, 1990; Collins *et al.*, 1983; Kent & Rosenbek, 1983; Mercaitis, 1983; Ryalls, 1981, 1987; Strand, 1987; Strand & McNeil, 1996). A more recent study by Seddoh *et al.* (1996b) examined temporal parameters of speech in subjects with AOS, CA and normal speech by means of acoustic analysis. The results of this study revealed that the apraxic subjects demonstrated longer and more variable stop gap, vowel and consonant-vowel durations than the normal and aphasic subjects, while the subjects with CA exhibited longer vowel and consonant-vowel durations than the normal speakers.

Strand and McNeil (1996) maintain that factors such as the specific vowel measured, method of elicitation of spoken stimuli, rate of presentation of stimuli and the degree to which the apraxic speakers have concomitant disorders might explain the discrepancy in results between various studies. From most acoustic studies it has been concluded, however, that persons with AOS have difficulty in planning durational control of speech segments. The fact that the subjects with AOS in the abovementioned studies exhibited deficits regarding vowel duration for multisyllabic, but not for monosyllabic words, could imply that utterance length and consequently motor complexity of an utterance influences the processing demands and consequently successful production.

Multisyllabic words are presumably motorically and linguistically more difficult to plan due to an increase in the coarticulatory possibilities, the number of core motor plans which need to be recalled, the demands regarding sequential organization of motor goals and IAS (Van der Merwe, 2002). Consequently longer utterances place greater demands on the speech production mechanism, causing persons with difficulty

regarding one or more of the stages involved in speech production to be more susceptible to breakdown. Since persons with AOS have difficulty with the motor planning of speech and specifically the sequencing of movement plans (Van der Merwe, 1997), they will presumably be more susceptible to breakdown during production of multisyllabic words than when producing monosyllabic words. Since vowel duration appears to be one of the temporal parameters of speech which is influenced by the context of production, it is a viable variable to study when investigating contextual influences on temporal parameters of speech production in AOS.

3.5.2.2 Other durational measures

Increased consonant duration has also generally been reported for persons with AOS compared to normal speakers (Bauman, 1978; Kent & Rosenbek, 1983), although consonant duration has been studied less often than vowel duration. Longer than normal segment duration, together with increased intersegment (Kent & McNeil, 1987; Mercaitis, 1983) and transition durations (Kent & Rosenbek, 1983) presumably result in the perceived slower than normal speaking rate in AOS (Kent & McNeil, 1987; Kent & Rosenbek, 1983; McNeil *et al.*, 1990a). In the study by Kent and McNeil (1987), the CA subjects also displayed abnormalities regarding segment and intersegment durations, implying the possibility of an underlying motor deficit contributing to the pathogenesis in this group of speakers.

The duration of many other aspects of production have been studied, including the duration of fricatives, syllables, words, pauses and interword intervals (Harmes *et al*, 1984; Kent & McNeil, 1987; McNeil *et al.*, 1990a; Square-Storer & Appeldoorn, 1991). Baum *et al.* (1990), in a study on fricative duration in Broca's, nonfluent and fluent aphasics, found similar results regarding absolute durations across subject groups, although normal speakers exhibited less variability. Code and Ball (1982) found that subjects with Broca's aphasia produced longer than normal durations for both voiced and voiceless fricatives in minimal pairs. Colson *et al*. (1986) found no significant differences between average syllable durations during repetition of nonsense disyllables. Harmes *et al.* (1984) also found no statistically significant differences between normal speakers and persons with Broca's aphasia regarding

absolute fricative durations during repetition of all target utterances in their study (single /z/-sound and /z/-words of one to three syllables in length).

Kent and McNeil (1987) on the other hand, found longer average segment durations in both AOS and CA in normal and fast rate conditions compared to normal speakers with the exception of one subject with AOS whose segment durations fell within the average normal duration at the control rate, but not at the fast rate. In the fast rate condition the CA subjects had average segment durations and ranges, which were comparable to those of the apraxic subjects in contrast to their average durations and variability which were more comparable to those of the normal subjects in the control rate. Mean intersegment durations for the AOS subjects in the control rate were longer than those of the normal and aphasic subjects. The aphasic subjects produced intersegment durations within the ranges of the normal subjects in the fast rate condition. Intersegment variability was greater for AOS subjects than for both CA and normal subjects.

Kent and Rosenbek (1983) reported durations of stop consonants and affricates which were comparable to those of normal speakers in monosyllabic words in subjects with AOS with "some" aphasia. However, almost all consonants in multisyllabic words were longer than normal in AOS subjects. The influence of word length on susceptibility regarding difficulty with temporal control is evident from this study. McNeil *et al.* (1990a) reported longer total utterance durations in subjects with AOS compared to normal and aphasic speakers in fast and control rate conditions, but not in the slow rate condition. One of the AOS subjects in the study by McNeil *et al.* (1990a) exhibited shorter than normal durations in the control rate condition. Square-Storer and Apeldoorn (1991) found that the polysyllabic word durations of two of their subjects with AOS were longer than normal, while those of a third subject were not. The subjects in the study by Square-Storer and Apeldoorn (1991) all differed regarding amount of variability with one AOS subject exhibiting little variability.

Mercaitis (1983) investigated the acoustic characteristics of the imitative speech of normals, aphasic and apraxic adults. Vowel duration, VOT, final consonant duration and syllable duration were measured within single syllables and two and three syllable segments. Verbal response time and intersyllable intervals were also analyzed.

Mercaitis (1983) found that apraxic adults exhibited significant differences from non-brain injured adults and aphasics regarding consonant-vowel-consonant syllable duration, final consonant duration and on variability of consonant-vowel-consonant productions. Regarding silent interval measures, the apraxic subjects differed significantly from the normal speakers and aphasics regarding verbal response time, intersyllable intervals and variability regarding these performances. Apraxic adults also differed from non-brain injured and aphasic adults regarding mean segment durations and in the variability of performance on these measures. From the results of her study, Mercaitis (1983) concluded that AOS is a motor programming disorder (as defined in a three-level model of speech production), separate from aphasia, even though the two disorders frequently co-occur.

3.5.3 Variability in temporal parameters

Variability in AOS and CA has been investigated regarding various aspects. These include variability regarding the type of errors produced during consecutive productions of a word (McNeil *et al.*, 1995), variability regarding error location in consecutive productions of a word (McNeil *et al.*, 1995), and variability regarding temporal measures on repeated productions of an utterance (token-to-token variability) (Kent & McNeil, 1987; McNeil *et al.*, 1989; Seddoh *et al.*, 1996a; Van der Merwe, 1986). The degree of variability regarding temporal measures is often used for differentiation of AOS and CA and for indicating motoric deficits (Ballard *et al.*, 2000). Consequently variability of temporal measures is of importance in the present study.

Several researchers have examined token-to-token variability of temporal parameters in speech production of subjects with AOS or CA (Kent & McNeil, 1987; Robin *et al.*, 1989; Seddoh *et al.*, 1996a, b). In a study by Kent and McNeil (1987) subjects with AOS and CA were found to display greater variability than normal speakers regarding VOT (all subjects with AOS and one subject with CA), segment durations and second formant transitions. The AOS subjects exhibited greater variability than the CA subjects regarding intersegment durations, especially in the fast speaking rate.

However, regarding variability of segment durations, the subjects with AOS and CA performed similarly in the fast rate.

In another study, Seddoh *et al.* (1996b) compared the temporal patterns exhibited by subjects with AOS and CA in order to determine similarities and differences and consequently make inferences about the underlying deficits in these two groups. Seddoh *et al.* (1996b) found that durational control was impaired in their apraxic subjects. This resulted in longer than normal mean durations regarding stop gap, vowel, and consonant-vowel productions, as well as increased token-to-token variability regarding these measures. The subjects with CA had longer than normal vowel and consonant-vowel durations, but their productions were not more variable than those of normal speakers. This was taken as evidence for a more stable motor control system in subjects with CA. Consequently Seddoh *et al.* (1996b) concluded that a phonological, rather than a motoric deficit, was present in the subjects with CA in their study.

McNeil *et al.* (1989) examined variability of peak articulatory velocities of the lower lip in subjects with AOS. Although the subjects with AOS exhibited normal velocities, their velocities were more variable than those of normal subjects. Seddoh *et al.* (1996a) studied temporal variability in subjects with AOS and reported greater variability than normal subjects regarding stop gap duration, steady-state vowel duration and total target word duration. Greater variability in subjects with AOS was not reported regarding VOT and second formant transition duration. One of the subjects in the study by Seddoh *et al.* (1996a) exhibited normal variability regarding all temporal parameters.

As is evident from the above discussion, increased variability on repeated trials of the same utterance is believed to reflect a motoric impairment and is often used for differentiation between AOS and CA. Subjects with AOS have generally been found to exhibit greater variability regarding temporal measures than normal speakers and speakers with CA (Kent & Rosenbek, 1983; McNeil *et al.*, 1989; Seddoh *et al.*, 1996b). Furthermore, greater variability is generally associated with instability of the speech motor control system (DiSimoni, 1974a, b; Janssen & Wieneke, 1987; Kent & Forner, 1980; Smith, 1992b, 1994; Smith & Kenney, 1994; Tingley & Allen, 1975;

Wieneke & Janssen, 1987). In this regard, Ballard *et al.* (2000) state that greater variability presumably leads to more frequent off-target productions in subjects with AOS than in normal speakers. It has been argued by Folkins (1985), however, that increased variability might be indicative of compensation when perceptually accurate responses need to be achieved in the presence of an unstable motor control system. In this sense the variability reflects the compensation employed to achieve a perceptually accurate response. Seddoh *et al.* (1996a) suggested that greater than normal variability in the presence of on-target speech might be used as a prognostic indicator in that persons exhibiting large variability and good compensation may recover better than persons who do not compensate well and cannot achieve perceptually accurate speech in the presence of increased variability.

3.5.4 Conclusion regarding the study of temporal aspects of speech production in AOS and CA

From the above discussion regarding the study of temporal aspects of speech production, it is evident that results regarding the duration of various segments, syllables and intersegment durations differ between various studies. The reason for this could be due to different stimuli used (nonsense versus meaningful utterances or mono- versus multisyllabic words), method of elicitation of test stimuli and criteria used for inclusion of subjects (Strand & McNeil, 1996). Furthermore, it is important to mention that although many of the studies investigating temporal aspects of speech production in persons with neurogenic speech disorders generally included individuals with CA, other fluent aphasics were also occasionally included. Furthermore, the subjects with AOS which were included in these studies often had accompanying Broca's aphasia, the severity of which could have contaminated results and conclusions about the nature of AOS. It is thus very important to clearly specify and control the criteria for inclusion of subjects who are to be representative of a specific speech or language disorder.

What is evident from the studies regarding temporal aspects of speech production in persons with either AOS or CA, however, is their potential to assist with the description of the speech characteristics in these groups of speakers. Furthermore,

such studies can aid with differential diagnosis, determination of the underlying nature of the disorders (phonemic versus motoric) and provision of information regarding the nature of normal and pathological speech motor control.

3.6 CONTEXTUAL INFLUENCES ON SPEECH PRODUCTION IN APRAXIA OF SPEECH

As discussed in chapter 2, certain contextual factors have the potential to increase the processing demands to the speech production mechanism necessitating the implementation of more complex control strategies by the brain (Van der Merwe, 1997). A characteristic of the normal motor control system is its extreme flexibility in achieving perceptually accurate productions under circumstances of increased processing demand. However, persons with deficits regarding speech and language processing will be more susceptible to breakdown when contextual factors increase the processing demands, since they might not be able to successfully exert more complex control strategies. The influence of these increased processing demands might consequently impact on the temporal parameters of speech production, especially in persons exhibiting difficulty regarding temporal control even in "normal" speaking situations.

Ballard and Robin (2002), as well as Van der Merwe (1997) underscore the importance of studying the effect of an individual to adapt to various contextual factors. Ballard and Robin (2002) mention phonetic contexts of speech targets (phonemic environment), speech rate and the setting in which the speech task is presented, for example, a quiet versus a noisy environment as potential contextual factors which could exert and influence on speech production. In this regard, these researchers stated that "By systematically examining a variety of conditions, the clinician has the potential to unveil weaknesses in the system that are disguised through compensatory, but perhaps inflexible, motor-based strategies" (Ballard & Robin, 2002:287). It is important to recognize the various contextual influences, since the way in which they are manipulated in therapy can influence the patient's performance and treatment outcome. Some contexts might be more challenging for

achievement of correct production and influence persons with different levels of breakdown in the speech production process differently.

In the following section, the study of specific contextual factors on speech production in AOS and CA will be reviewed. A specific contextual factor will presumably influence both speech and language processing, since it is difficult to separate linguistic and motoric aspects during speech production (Robin *et al.*, 1997). The contextual factors which will be discussed in the following section include, sound position in a word, frequency of occurrence of the sound in the specific language, meaningful compared to nonsense utterances, word length, distance of articulatory movement for the upcoming sound, grammatical class, utterance length, linguistic complexity, level of voluntary initiation of utterances and speaking rate. Some of the studies which will be discussed examined more than one of these contextual factors.

3.6.1 Sound position in a word

Some researchers have reported that more errors are made on initial than on final sounds (Shankweiler & Harris, 1966; Trost & Canter, 1974), while others did not find any difference regarding correct production depending on the position of the sound in the word (Dunlop & Marquardt, 1977; Johns & Darley, 1970; LaPointe & Johns, 1975). The finding that persons with AOS exhibit more difficulty regarding initial sounds could be related to the difficulty they have with initiation of speech production.

3.6.2 Frequency of occurrence

Trost and Canter (1974) found that the more frequent a sound occurs in a language, the easier it is to produce. This finding probably relates to the concept of automaticity, in that sounds or utterances that are produced more frequently become automatized and do not require conscious processing or control. Utterances which occur frequently are then also familiar and usually overlearned to a greater extent than infrequently occurring utterances (Van der Merwe, 1997, 2002). On the other hand, sounds or utterances which are used less often require more conscious processing

during production. Conscious processing, in turn, utilizes more processing resources (Kent, 1990). Resource capacity might be more easily exceeded in persons with deficits regarding one or more of the stages of speech production, since more than normal resources are already required for allocation to the stages with which difficulty is experienced. The motor plan of speech sounds which are less familiar is also presumably less firmly established, making retrieval of the core motor plan and adaptation thereof to the phonetic environment, as well as the other operations involved in motor planning and/or programming of speech more difficult.

Greater difficulty might be particularly evident in persons with deficits regarding the motor planning and/or programming of speech. For persons with AOS who exhibit a deficit regarding the motor planning of speech (Van der Merwe, 1997), production of speech sounds which occur less frequently in a language will be less automatized and consequently motorically more difficult. Persons with PP might also exhibit deficits regarding production of less frequently occurring speech sounds, since these sounds might pose greater demands regarding phonological processing as well.

3.6.3 Meaningfulness of utterances

Johns and Darley (1970) found that their subjects with AOS produced more errors on repetition of nonsense words than on repetition of real words. Martin and Rigrodsky (1974a, b) and Martin *et al.* (1975) also found that persons with AOS made more errors on meaningless utterances than on utterances which are meaningful.

The meaningfulness of utterances can also be related to the concept of automaticity, as well as to the novelty of the response. Meaningful words are presumably more automatized, since they are used more often than nonsense words which are compiled for experimental purposes. In most cases experimental utterances have not been previously encountered or produced by the subjects in a particular study. Because meaningful words might be overlearned to great extent, they do not require conscious control and consequently do not necessitate more than normal resources. Unfamiliar or nonsense utterances presumably require more conscious processing and allocation of more attentional resources. As mentioned, resource capacity might be more easily

exceeded in persons with AOS and those with PP, since more than normal resources are already required regarding the stages of speech production with which difficulty is experienced.

Furthermore, the motor plan for meaningful words is also presumably more firmly established, whereas the motor plan for novel/nonsense utterances has to be constructed anew. During production of nonsense utterances, persons with difficulty regarding motor planning, will thus experience more difficulty with the operations involved in motor planning, for example, adaptation of the core motor plan to the phonetic environment, since the motor plan for such utterances is novel and less automatized. It is suspected that nonsense utterances will also pose greater demands regarding phonological processing and consequently persons with PP would also presumably experience greater difficulty with their production.

3.6.4 Articulatory "distance"

Another factor which has been found to influence the accuracy of articulation is the distance which the articulators have to move from the production of one sound to the next. In this regard, it has been found that the further the distance of the articulation point from one sound to the next, the more likely an error is to occur (Wertz *et al.*, 1984). Since persons with AOS have difficulty with motor planning and consequently with accurate specification of the temporal and spatial parameters, together with difficulty adjusting the individual core motor plans to the phonetic environment (Van der Merwe, 1997), it can be assumed that the further the spatial targets which need to be reached are from each other, the more opportunity there is for breakdown to occur, since there is more "time" and "distance"/"space" in which the movements of the articulators need to be coordinated. Persons with AOS might be less skilled in specifying the spatial and temporal parameters of speech production in such a situation, resulting in inefficient or inaccurate movements, which will presumably result in sound distortion. Furthermore, it might also be more difficult to adapt the core motor plans of each phoneme to the phonetic environment when the place of articulation of the sounds is "further" from each other. Articulatory distance should

presumably not negatively influence speech production of persons with linguistic level deficits.

3.6.5 Grammatical class

Many years ago attempts were made to determine the effect of specific linguistic variables on articulatory accuracy in AOS. Researchers attempted to determine if AOS contains intrinsic linguistic components as part of its underlying pathology or if it is influenced by semantic and syntactic factors. Hardison, Marquardt and Peterson (1977) suggested that investigation of linguistic aspects of the disorder would help resolve this issue. If language variables influence motor planning of speech, therapy aimed at improvement of articulatory accuracy need to consider these linguistic variables (Hardison *et al.*, 1977), together with motor learning principles when compiling treatment regimes.

An example of a linguistic factor which was studied is grammatical class. The influence of this variable on frequency of error productions in AOS has rendered inconsistent results. Deal and Darley (1972) reported that grammatical class alone did not exert an influence on errors, but that when it was combined with one or more other factors, namely, the difficulty of the initial phoneme (affricate, fricative or consonant cluster) or the length of the word, the errors increased.

In another study, Dunlop and Marquardt (1977) examined the effect of articulatory and linguistic variables on speech production by analyzing the errors of ten apraxic speakers on a single-word production task. These researchers wanted to determine the effect of grammatical word class (noun, verb or adjective), phoneme position and phoneme difficulty on errors in AOS, as well as the relationship between word abstraction and error production in these speakers. Dunlop and Marquardt (1977) found that the difficulty of the phoneme, but not the position of the phoneme in a word affected the errors of the apraxic speakers significantly. Furthermore, individual subjects were affected differently.

In the second part of their study, Dunlop and Marquardt (1977) attempted to determine the relationship between the abstraction level of a word in noun, verb and adjective grammatical categories and error production of these words in AOS. Nouns were graded as being the least abstract, followed by verbs and adjectives. These researchers found that a low, but significant positive correlation existed between apraxic error scores and single word abstraction ratings, although correlations for the grammatical classes decreased with increases in abstraction. These researchers concluded that language deficits might be associated with AOS and that "impaired motor speech programming may be affected by linguistic and articulatory variables" (Dunlop & Marquardt, 1977:29). The researchers themselves did, however, mention that their subjects might have had concomitant aphasia and that this could have influenced the results of their study. The need for additional studies of the phonemic and non-phonemic aspects of AOS and its relationship to other language processes was noted.

Hardison *et al.* (1977) studied the effect of selected linguistic variables on apraxic speech errors. These variables included word position (nouns in the beginning or end position in a sentence), word abstraction (concrete, abstract or nonsense) and sentence voice (active or passive). From the results of their study, these researchers concluded that the linguistic variables they investigated, significantly affected the ability of the apraxic speakers to program the movements for speech production. They concluded that "articulatory accuracy is at least influenced by semantic and syntactic factors", that AOS probably contains linguistic components as part of its pathogenesis and that speech motor planning is thus "part of an interlocking language system" (Hardison *et al.*, 1977:341).

It must be mentioned, however, that the subject selection criteria for the subjects in the study by Hardison *et al.* (1977), most probably resulted in the inclusion of persons with aphasia. Although subjects had to have had good auditory comprehension abilities, they had to exhibit a predominance of substitution errors and periods of error-free speech during spontaneous utterances. As was established in later years, apraxic speakers exhibit distortion as a predominant speech characteristic and phoneme substitution is primarily characteristic of certain types of aphasia (Odell *et al.*, 1991a, b).

It is quite possible that linguistic factors might impact on motor control processes, since language and motor processes presumably share processing resources (Strand & McNeil, 1996). In AOS, more complex linguistic structures might require more processing resources. The resource capacity of speakers with AOS might be more easily exceeded in the presence of difficulty with the motor processes of speech production, since more than normal resources might already need to be allocated to the deviant processes regarding speech motor control. Consequently erroneous production might result more easily in these speakers.

3.6.6 Length of utterance

It has generally been found that persons with AOS make more errors on multisyllabic words than on monosyllabic words (Johns & Darley, 1970; Shankweiler & Harris, 1966). Furthermore persons with AOS are known to experience more difficulty with the production of longer words (Kent & Rosenbek, 1983; McNeil *et al.*, 1997; Strand & McNeil, 1996). Since persons with AOS have difficulty with the motor planning of speech, it stands to reason that production of longer utterances would be more problematic since these utterances are also motorically more complex (Van der Merwe, 2002). Longer utterances increase the processing demands to the speech production mechanism, since more core motor plans need to be recalled, sequential organization of all the motor goals increases, the potential regarding coarticulation increases and IAS becomes more complex (Van der Merwe, 2002). Longer utterances will also presumably increase the demands regarding linguistic-symbolic planning, since more phonemes need to be selected and sequenced. Consequently persons with PP will also presumably experience greater difficulty regarding production of longer utterances.

3.6.7 Linguistic complexity

Strand and McNeil (1996) investigated the effects of increased utterance complexity and length on temporal parameters by means of acoustic analysis of utterances that vary in type. Vowel duration and two between-word segment durations were

measured during production of three response types, namely, words, word-strings and sentences. Eight experimental conditions were employed, which included two length conditions for word-strings, three length conditions for words, and three length conditions for sentences.

The results of the study by Strand and McNeil (1996) indicated that the subjects with AOS consistently produced longer vowel and between-word segment durations in sentence contexts than in word contexts. For the subjects with AOS, intra- and inter-subject variability for between-word segments were also greater for sentences compared to word conditions. These researchers concluded that the differences which were found regarding duration and variability in sentence production versus word and word-string production imply "different mechanisms for executing motor programs for varying linguistic stimuli" (Strand & McNeil, 1996:1018). Furthermore, these researchers speculated that the reasons for linguistic factors influencing motor control could be due to the sharing of resources amongst language formulation and motor control processes. In other words, if difficulty regarding a specific level of the speech production process is present, an increase in processing demands caused by any contextual factor will presumably lead to breakdown regarding speech production in a specific subject, since resource capacity will be more easily exceeded in these circumstances.

3.6.8 Level of voluntary initiation of actions

It has been demonstrated that speakers with AOS are less prone to errors during automatic-reactive speech than during volitional-purposive speech (Darley, 1982). More automatic utterances, for example, reciting the days of the week or inserting comments, for example, "I can't say that" are presumably more automatized and overlearned. Consequently these motor plans can be retrieved and executed with a great degree of automaticity. Volitional-purposive speech requires conscious processing regarding language and/or motor processes and consequently more resources need to be allocated during execution of this task (Kent, 1990). The better performance of persons with AOS on more automatic speech tasks is contradictory to the dual-route theory proposed by Whiteside and Varley (1998) proposing an inability

of persons with AOS to access the direct route successfully, since automatic utterances are presumably accessed via the direct route (Ballard *et al.*, 2001).

3.6.9 Speaking rate

The intensity and duration of activity in individual muscles changes with increases in speaking rate, although it is proposed that the relative timing of muscle activity remains constant (Kelso *et al.*, 1983). An increase in speaking rate necessitates that the temporal and spatial parameters of the core motor plan be adjusted and consequently it entails more than just an increase in the speed of firing of consecutive motor impulses. Speech rate can thus be seen as a context for speech production (Van der Merwe, 1986). The reason for employment of an increase in speaking rate in the study of speech motor control in persons with speech and/or language disorders, is the fact that it presumably increases the demands regarding speech and/or language processing. Consequently an increase in speaking rate has the potential to more readily reveal deficits in persons with difficulty regarding speech and/or language processing. Studying the effect of speech rate alterations on articulatory timing can tell us more about the motor disturbance in persons with neurogenic speech disorders, since an increase in speaking rate places higher demands on the speech production mechanism and consequently on speech motor control (Kent & McNeil, 1987; McNeil *et al.*, 1990a).

A few acoustic studies requiring rate adjustments have been performed and will be discussed briefly. Studies in which speech rate was utilized generally concluded that subjects with AOS have difficulty adjusting their speaking rate, especially when speaking rate has to be increased. This has been taken as evidence for a motor component underpinning the nature of the speech disorder in AOS (Kent & McNeil, 1987). CA subjects are generally more successful at increasing syllabic rate and this has led researchers to conclude that these subjects "retain a motoric flexibility that is lost in apraxia of speech" (Kent & McNeil, 1987:215). McNeil *et al.* (1997) recently reported that persons with AOS have difficulty increasing rate without compromising phonemic integrity, while persons with PP exhibit a variable ability to increase rate, but can maintain phonemic integrity.

Kent and McNeil (1987) performed an acoustic study to obtain information about segment and intersegment durations in normal speakers, persons with CA and persons with AOS. In order to cause phonetic-motoric alterations the subjects had to produce speech material at two different speaking rates, namely at a control and fast rate. It is assumed that producing the same material, using different speaking rates "provides a method for manipulating the phonetic level of speech production while theoretically, controlling the phonemic/linguistic level" (McNeil *et al.*, 1990a:136). Kent and McNeil (1987) were motivated by the hypothesis that patients with disorders at the phonetic or motor level of the speech production process would perform differently from normal subjects when rate is manipulated, whereas subjects who have phonological level impairments would maintain relative timing patterns similar to those of the normal subjects, despite changes in speaking rate.

Although it could be argued that an increase in speaking rate, could place higher demands on linguistic processing as well (Fossett *et al.,* 2001), researchers have generally excluded the presence of a phonological level deficit when timing deficits were observed in productions of an on-target response. In the presence of perceptually accurate speech, timing deficits are generally ascribed to a aberrant motor control (Kent & McNeil, 1987; McNeil *et al.*, 1990a). Kent & McNeil (1987) thus used rate manipulation to investigate the nature of the underlying pathology (phonetic versus phonemic level of impairment) in persons with neurogenic speech and language disorders.

Kent and McNeil (1987) reported that both the AOS and aphasic subjects had difficulty with rate manipulation. From this result, these researchers concluded that the difficulty these subjects had experienced with rate alterations seemed to imply a "motoric inflexibility" in these speakers. The subjects with CA were, however, more successful than those with AOS in increasing speaking rate and Kent and McNeil (1987:215) concluded that “in this respect the conduction aphasics seem to retain motoric flexibility that is lost in apraxia of speech”. It must be emphasized, however, that a degree of flexibility is still maintained in subjects with AOS and that inflexibility does not imply a complete inability. Kent and McNeil (1987) concluded that "the nature of the disordered process in both AOS and CA has phonetic and

motoric components" and therefore used the term "phonetic-motoric" as a label for the impairment in AOS and CA (Kent & McNeil, 1987:211). This conclusion was also supported by the other motoric abnormalities which were observed in the CA and AOS subjects in their study, namely, abnormal VOT values, variability in formant trajectories and long pauses. These researchers stated, however, that their findings do not imply that AOS and CA are one and the same impairment.

McNeil *et al.* (1990a) performed a study with the main objective being replication of the study by Kent and McNeil (1987) in order to gain insight into "the nature of speech motor control" in persons with AOS and persons with CA. The same subjects as in the Kent and McNeil (1987) study participated in this study, but the two studies differed regarding test utterances and method of analyses. Rate was also manipulated in the study by McNeil *et al.* (1990a) and only on-target utterances were used for analysis. McNeil *et al.* (1990a) made the assumption that when on-target production was achieved and relative timing deviated from that of the normal group, the deviant timing could be attributed to difficulty regarding motor control.

The results of the study by McNeil *et al.* (1990a) indicated that both subjects with AOS and subjects with PP had trouble adjusting their speaking rates, especially when speaking rate had to be increased. The subjects with AOS experienced greater difficulty than the subjects with CA regarding rate adjustments, implying that additional motor control difficulties existed in the subjects with AOS. These results were taken as rendering support for the notion that both AOS and CA speakers exhibit motor control deficits, which possibly account for some of their speech production errors (McNeil *et al.*, 1990a). A study by Robin *et al.* (1989) also found that persons with AOS have difficulty adjusting speech rate for syllable- and sentence-level material, despite exhibiting normal velocity in the lower lip and intact coordination of the movement of the upper and lower lips.

It is important to remember that when speaking rate is increased, higher demands are also presumably placed on phonological planning, since the operations involved in this stage of the speech production process also need to be performed at a greater than normal speed. Kent and McNeil (1987:214) have argued, however, that difficulty regarding phonological planning might have “motoric consequences in the form of

abnormal temporal patterns" and that separation of between motor realization and phonological representation might be invalid. This implies that disorders with different underlying impairments might be manifested in much the same way in the temporal parameters of speech production. If a perceptually on-target response is produced, however, one can conclude that the linguistic-symbolic stage of the speech production process was completed successfully, despite the increased demands induced by an increase in speaking rate. Deficits which are identified regarding the temporal parameters of speech production could thus presumably be attributed to difficulty at the level of motor planning and/or programming as defined in the four-level framework of speech sensorimotor control proposed by Van der Merwe (1997), since durational aspects are specified and adapted during these stages of the speech production process.

The studies by Kent and McNeil (1987) and McNeil *et al.* (1990a) demonstrate the use of rate manipulation to assess the proficiency of the speech motor systems of pathological speakers. It is thus evident that speaking rate can be viewed as a context for speech production exerting an influence on processing demands. These increased demands can result in susceptibility to breakdown in persons with difficulty regarding speech and/or language processing. Employment of changes in speaking rate consequently has the potential to reveal deficits regarding motor control in persons with neurogenic speech and/or language disorders.

3.6.10 Speech production in first versus second language in bilingual speakers with neurogenic speech and/or language disorders: A proposed context for speech production

It is not known what the effect of producing speech in L2 is on the motor planning of speech, but it is suspected that, speech production in L2 by a bilingual speaker might be a more demanding speaking context than speech production in L1 (Van der Merwe & Tesner, 2000). This might be especially true in persons who already have difficulty regarding speech and language processing. Speech production in L2 is hypothesized to increase the processing demands for two reasons. Firstly, L2 might contain sounds which are not part of the speaker's L1 repertoire, causing articulation of these sounds

to be motorically more difficult. The reason for such sounds being motorically more difficult is the fact that the motor plans for these sounds have not been as firmly established as those of L1 sounds and consequently these plans are less automatized. Even if the sounds of L2 are contained in L1, the words in L2 are novel compared to L1 words and production of L2 words is consequently less automatized. Furthermore, other operations involved in the motor planning of speech, for example, adapting sounds to the phonetic environment will not be as automatized as in L1, since the combination of phonemes (sequencing of phonemes) in L2 words is different than in L1 (Van der Merwe & Tesner, 2000). Secondly, on a linguistic level of processing, message formulation in L2 might require more conscious processing, since the vocabulary and grammatical aspects of L2 are not as familiar to the bilingual speaker as those of L1. More conscious processing is thus required for accurate selection of words and formulation of grammatically correct sentences.

Speech production in L2 is thus presumably not as automated as speech production in L1 in the bilingual speaker, regarding both linguistic and motor processing, necessitating more conscious processing regarding both these processes (Van der Merwe & Tesner, 2000). More conscious processing consequently requires allocation of more attentional resources. From this perspective, speech production in L2 might be more demanding for persons with deficits regarding motor planning and/or programming, as well as for those with deficits regarding linguistic-symbolic planning, since more than normal resources already need to be allocated to these disrupted processes. Resources might consequently be more easily exceeded when the processing demands are increased in persons with neurogenic speech and language disorders. The result of these increased demands regarding motor and linguistic processing might be visible on a motor execution level in the spatial and temporal parameters of speech production. Speech production in L2 might thus have consequences for the motor control of speech (Klein *et al.*, 1995; Van der Merwe & Tesner, 2000).

The source of speech errors in neurogenic speech and language disorders, such as, AOS and PP is either ascribed to the phonologic or motoric level of the speech production process. When speech and language processing demands increase, speakers with speech or language disorders will be more susceptible to breakdown

regarding their speech production. In order to learn more about the underlying nature of the disorder in AOS and to contrast this disorder with PP, it is necessary to determine the influence of various contextual factors on speech production in these groups of speakers. If persons with AOS find production of a phonetically similar utterance in L2 more difficult than in L1 compared to normal speakers, it can be concluded that language as a context for speech production exerts an influence on the motor control of speech. The language of the speaker could consequently then be seen as a context influencing motor performance. Due to the frequency of bilingualism in AOS, a systematic study of the effect of L1 versus L2 speech production in persons with AOS is imperative.

Although bilingualism in aphasics has been widely studied, bilingualism in motor speech disorders, such as, AOS, has not received attention, apart from a study by Van der Merwe and Tesner (2000) who examined perceptual characteristics in a bilingual speaker with AOS and the effect of non-language specific treatment on perceptual errors in L1 (Afrikaans) and L2 (English) in this speaker. In this regard Van der Merwe and Tesner (2000:87) stated "Bilingual apraxia of speech seems to be a reality as much as bilingual aphasia. To the disadvantage of clients with AOS, this issue was ignored for much too long".

3.6.11 Conclusion regarding contextual influences on speech production in neurogenic speech and/or language disorders

As is evident from the above discussion, certain contextual factors can increase the processing demands imposed on the speech production mechanism. In other words, speech production in certain contexts appears to be more challenging to the speech production mechanism than in others. The processing demands are increased by the fact that the contextual factors impact on one or more levels of speech and language processing. This impact, in turn, increases the task complexity, making persons with difficulty regarding one or more of the stages of the speech production process more susceptible to breakdown. The increased processing demand which the various contextual factors impose can mostly be related to the concept of automaticity, the

novelty of the response and/or motor complexity of production. These factors, in turn, increase the task complexity and susceptibility to breakdown.

Another explanation for the susceptibility to breakdown occurring in persons with neurogenic speech and language disorders relates to allocation of attentional resources. Ballard *et al.* (2000:983) state it is necessary to "conceptualize AOS as a disorder of motor control that also may have an impact on the availability and allocation of attentional resources for performing and adapting actions". It has been proposed that persons with neurogenic speech and language disorders, specifically AOS and CA, might have difficulty regarding availability and allocation of attentional resources (Clark & Robin, 1998; Kent & McNeil, 1987; Rogers & Storkel, 1999). Consequently difficulty with speech production is experienced when greater demands are placed on the speech production mechanism, since resource capacity is more easily exceeded in these circumstances in persons with difficulty regarding one or more of the stages of the speech production process. The reason for exceeding of resources is the fact that more than normal resources already need to be allocated to the levels of the speech production process where difficulty is experienced.

Normal speakers presumably exhibit greater flexibility regarding adaptation to more demanding speaking contexts. Consequently normal speakers will not experience problems with on-target production when the demands of the speaking context increase with, for example, an increase in speaking rate. The speech production system of a normal speaker can thus probably be "loaded" to a greater extent than that of a person with a compromised speech production mechanism. This is evident from the flexibility these speakers display by the achievement of on-target speech in, for example, mechanical perturbation circumstances (Smith, 1992a), when producing linguistically more difficult utterances (Strand & McNeil, 1996) or when speaking at a faster than normal rate (Ostry & Munhall, 1985).

Different tasks or contextual factors impose different processing loads (McNeil *et al.*, 1991a). It should be interesting to see which contextual factors lead to breakdown in persons with deficits at different levels of the speech production process. Persons with breakdown at different levels of the speech production process might react differently when greater demands are placed on the speech production mechanism by

various contexts. Examining the nature of the breakdown and determining which contexts are more difficult to adjust to for persons with specific speech and language disorders, has the potential to shed light on the underlying nature of these disorders.

The present study aims to determine the effect of speech production in L1 versus L2 as a context for speech production on specific temporal parameters of speech in persons with AOS as measured in the acoustic signal using spectrographic analysis. Persons with a preponderance of PP in their speech will also be included in the study, since their level of breakdown is presumed to be regarding linguistic-symbolic planning (Van der Merwe, 1997), which is distinct from the level of breakdown in persons with AOS. Inclusion of persons with PP thus allows for contrasting of results and for clearer delineation of AOS. To further increase the processing demands in both languages, a faster than normal speaking rate will also be employed, since this might reveal difficulty with speech production in L2 more readily.

3.7 CONCLUSION

Various theories, frameworks and models have been proposed to clarify and explain the underlying nature and observed phenomena in AOS. These theories, frameworks and models have led to many research studies attempting to define AOS and describe its salient characteristics. Since persons with AOS are generally described as exhibiting difficulty with temporal control, temporal parameters of speech production are often investigated in an attempt to elucidate the nature of the disorder and to contrast it with other neurogenic speech and language disorders with which it shares common characteristics. Various contextual influences have been identified to exert an influence on the processing demands imposed on the speech production mechanism (Van der Merwe, 1997). These contextual factors impact on the parameters of speech production and need to be studied to learn more about the contextual factors which subject persons with AOS to erroneous production. The effect of L1 versus L2 as a context for speech production has not been investigated in AOS. The need for determination of the influence of L1 versus L2 production becomes evident when one considers the number of bilingual speakers with AOS.

3.8 SUMMARY OF CHAPTER THREE

In this chapter, AOS and the speech disorder in persons with predominant PP were defined. Models, theories and frameworks which have been proposed to explain the underlying nature of AOS were reviewed. From this review it became evident that the context of speech production can influence the achievement of perceptually on-target speech. Studies investigating specific parameters of articulatory timing in AOS and CA, namely interarticulatory timing (VOT) and duration, as well as studies on variability were reviewed. Thereafter the influence of various contextual factors on speech production in AOS and PP was discussed. From the discussion, it became evident that there is a need for the study of the effect of L1 versus L2 on specific temporal parameters of speech production in AOS and PP in order to learn more about the underlying nature of these disorders, for determination of qualitative differences between them and to obtain information about normal and pathological speech motor control.