The effect of speaking rate on serial order sound-level errors in non-brain damaged participants and persons with aphasia

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While many speech errors can be generated at either a linguistic or motoric level of production, phonetically well formed sound-level serial order errors are generally assumed to result from disruption of phonologic encoding (PE) processes. An influential model of PE (Dell, 1986; Dell, Burger & Svec, 1997) predicts that speaking rate should affect the relative proportion of these serial order sound errors (anticipations, perseverations, exchanges). These predictions have been extended to, and have special relevance for persons with aphasia (PWA) because of the increased frequency with which speech errors occur and because their localization within the functional linguistic architecture may help in treatment management. Supporting evidence regarding the effect of speaking rate on phonological encoding has been provided by studies using young normal language (NL) speakers and computer simulations. Limited data exist at present for older NL users and no group data exist for PWA.

The purpose of this study was to examine the effects of speech rate on the ratio of phonological sequencing errors (*anticipation/exchange (AE), anticipation/perseveration) (AP))* and other error types (*vocal reaction time* and *distortion*) in non-brain-damaged individuals and in persons with aphasia who were without concomitant motor speech disorders. Sixteen NL users and 16 PWA performed a phonologically challenging (tongue twister) speech production task at their typical and two faster speaking rates. A significant effect of rate was obtained for the *AP ratio* but not for the other comparisons. Contrary to the predictions of the model, the AP ratio increased with faster speaking rates**.** There was also a significant effect of rate and group for the VRT measure.

The results for the serial order error ratios did not provide support for the model derived predictions regarding the direction of change for error type proportions. However, the significant effect of rate for the AP ratio provided support that changes in speaking rate did affect phonological encoding. Additionally, the results suggest that the relationships among slow post-selection inhibition and normal residual activation functions postulated to create an increase in perseverations relative to anticipation serial order errors, needs to be reconsidered within the Dell, et al. (1997) model.

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1.0 INTRODUCTION

Speech production errors have been studied extensively in both normal and pathological language populations. Investigators have examined production to inform linguistic theory (Celce-Murcia, 1973; Fromkin, 1973), to understand normal production processes (Garrett, 1980; Levelt, 1989; MacNeilage, 1970; Stemberger, 1985), to understand the level of disrupted production processes in pathology, and to contribute to the nosology of speech and language disorders (McNeil, Doyle, & Wambaugh, 2000; McNeil & Kent, 1990; McNeil, Robin, & Schmidt, 1997; Rogers & Storkel, 1998,1999;Whiteside & Varley, 1998). The value of studying speech errors, was recognized at least as early as the 1800s as evidenced by the works of Jackson (as cited in Marshall & Newcombe, 1988) and Merringer (as cited in Celce-Murcia, 1973) and has continued through the 1900s in the works of Freud (1901/1951), MacNeilage (1970), Fromkin (1973), Dell (1986), Schwartz, Saffran, Bloch, and Dell (1994), McNeil and Kent (1990), Rogers and Storkel (1998,1999) and others. Speech errors have been analyzed with perceptual (Blumstein, 1973; Dell, 1986; Garnham, Shillcock, Brown, Mill, & Cutler, 1982; Miller, 1995; Shriberg & Kwiatowski, 1982), acoustic (Kent & Rosenbek, 1983; Liss & Weismer, 1992; Weismer & Fennell, 1985), kinematic (Forrest, Weismer, & Turner, 1989; Murdoch & Goozee, 2003) and electromyographic (Strauss & Klich, 1999) measures. Both descriptive (Boomer & Laver, 1973; Cohen, 1973; Fromkin, 1973; Merringer, as cited in Celce-Murcia, 1973) and experimental (Dell, 1984; Dell, Burger & Svec, 1997; Motley, 1985;

Schwartz, et al., 1994) methods have been used to collect speech error data. Additionally, a variety of contexts (e.g., syllables, words, sentences), tasks (e.g., priming, repeating, reading, picture description) and types of stimuli (e.g., tongue-twisters, word pairs) have been used to elicit production errors.

Sound-level production errors frequently occur in both normal (Boomer & Laver, 1973; Fry, 1973) and pathological populations. In the individual with uncompromised production processes, sound-level errors have been viewed as a vehicle through which normal production processes may be understood (Buckingham, 1980; Cohen, 1973; Shattuck-Hufnagel, 1987). Saffran (1980) suggested that understanding the mechanisms that contributed to the sound-level speech production errors of persons with aphasia (PWA) might help investigators develop a better understanding of those factors involved in normal speech production. An increased understanding of the mechanisms and factors that contribute to speech production errors in compromised as well as normal speech production systems may result in a better understanding of the interaction of different components of the speech production system as well as influence the development of theories for diagnosis and treatment of disordered speech production.

While speech production errors occur at all levels of the cognitive, linguistic and motor systems in a number of pathological conditions, in addition to normal non-pathological states, the present discussion will focus primarily on those errors produced by PWA. Aphasia is a cognitive-linguistic disorder that historically, has been defined in many different ways (McNeil, 1982). Traditionally, aphasic behaviors have been organized into types of aphasia with a core set of salient behaviors or modality differences characterizing the patterns that are unique to each type. Although aphasia is, by definition, not a motor disorder, types of aphasia have been in part, defined by a variety of speech motor as well as language characteristics (McNeil, et al., 1997). Even though the traditional classification system has come under criticism (Darley, 1982; Schwartz, 1984), these categories continue to be used to select groups for study and treatment. The inclusion of motor level characteristics in determining types of aphasia has led to confusion in separating characteristics associated with particular "types" of aphasia, specifically Broca's and conduction aphasia (CA), from other disorders such as neurogenic stuttering, some dysarthrias and particularly apraxia of speech (AOS) (McNeil & Kent, 1990). This confusion is heightened by the fact that aphasia and AOS frequently co-occur and that there is a historical lack of agreement about the nosology of AOS and its defining characteristics (McNeil, et al., 1997; Rosenbek, Kent, & LaPointe, 1984). According to McNeil, et al. (1997), the traditional phonologic, phonetic and prosodic criteria used for differential diagnosis between Broca's aphasia and AOS are largely undifferentiated. These authors argue that individuals diagnosed with Broca's aphasia may or may not have AOS, but are likely to have motor speech deficits in addition to their aphasia. The presence of motor speech deficits could account for the short phrases, prosodic, and sound-level errors characteristic of the traditional classification system. Contrastively, CA, as well as other subtypes of aphasia (i.e., anomic, transcortical sensory, Wernicke's), is not primarily distinguished by characteristics that may be attributed to motor level impairment (Goodglass, 1992; Kohn, 1984; Shallice & Warrington, 1977). While there is some evidence that individuals diagnosed with CA may have some degree of motor level deficit (Kent & McNeil, 1987; McNeil, Liss, Tseng, & Kent, 1990), in general, motor level characteristics are not a part of its characterization. Instead, CA is typically characterized as a "fluent aphasia" (Goodglass, Kaplan, & Barresi, 2001, p. 71) and thus presents with generally uncompromised speaking rate, grammatically correct utterances and the presence of phonemic paraphasias, but correctly articulated speech sounds (Goodglass, 1992). While the deficits in what is traditionally classified as Broca's aphasia stem from both disrupted cognitive-linguistic and motor level processes, the primary deficit in CA is typically attributed to the cognitive-linguistic level of production. It is important to acknowledge and disambiguate the influence of cognitive-linguistic and motor level processes for certain types of speech production errors especially those generated at the sound level. Distinguishing the relative contributions of the various cognitive, linguistic and motoric processes to speech production errors may enhance their differential diagnostic power, provide knowledge about the level(s) of disruption and impaired mechanisms in the errors produced by persons with aphasia, direct better their treatment, as well as contribute to a greater understanding of the normal production process.

A number of cognitive-linguistic and motor variables have been identified as relevant for the accurate production of speech sounds. These variables have often been formalized within the context of a speech production model. While models differ on how they conceive of the speech production process, most posit different production processes as occurring at different levels (e.g., conceptual, semantic, syntactic, phonologic, motoric) within the production system. It is within these levels that variables, which may influence accurate speech sound production, have been identified. These variables include, but are not limited to verbal working memory, lexical (e.g., word, non-word), semantic (e.g., frequency, thematic role), and phonologic (e.g., form, similarity) factors, size of the target unit, time available for encoding, speaking rate and the integrity of the motor system. It is acknowledged that this is an incomplete list of potential influences on production accuracy, and this discussion will not address all of the variables mentioned. Based on those parameters most frequently discussed relative to the sound production errors that occur in the cognitive-linguistic disorder of aphasia, the most relevant variables are those associated with phonologic encoding (including verbal working memory and speaking rate). This discussion will focus on the process of phonologic encoding and how speaking rate interacts with and/or affects that process. This discussion will be limited to those variables that arise from the phonologic to motoric production levels, as described by Dell (1986), Levelt (1989) and others (Levelt, Roelofs, & Meyer, 1999; Roelofs, 1997b; Shattuck-Hufnagel, 1983). In addition to discussing speaking rate, an overview of some general and level-specific speech production models will be provided so that the concepts of phonologic and motor-level processes and impairments can be conceptualized, contextualized and specified.

Investigators have examined the variable of speaking rate relative to its effect or relationship with various acoustic (Gay, 1978; Kent & McNeil, 1987; McNeil, Liss, et al., 1990; Tsao, Weismer, & Iqbal, 2006) and kinematic (Adams, Weismer, & Kent, 1993; Byrd & Cheng, Tan, 1996; Shaiman, 2002) variables. It also has been investigated for how it affects or is affected in the speech production of various pathologies (Andrews, Howie, Dozsa, & Guitar, 1982; Kent & McNeil, 1987; McNeil, Liss, et al., 1990; Turner & Weismer, 1993). Investigations that evaluate the manner in which speaking rate affects or is affected by other cognitive-linguistic variables are few, however, and tend to focus on the relationship of speaking rate and speech intelligibility (Krause & Braida, 2002, 2004), listening rate preferences (Lass & Prater, 1973), or language comprehension and speech intelligibility (Riensche, Wohlert, & Porch, 1983). Few studies have examined the effect of speaking rate manipulation at the level of phonological encoding (Dell, 1986; Dell, 1990; Wilshire & McCarthy, 1996).

The purpose of this study was to explore the effects of speech rate as one independent variable potentially capable of disambiguating the proper assignment of sound-level speech production errors to the phonologic encoding level in persons with normal language processing and in persons with aphasia. These topics will be discussed relative to the type and nature of sound-level speech production errors in both populations. Included in this discussion will be an examination of the variables of verbal working memory and speaking rate as they relate to phonologic encoding. This chapter will:

1. Review some general models of speech production.
2. Review some select models of phonologic encoding.
3. Provide a rationale for choosing one particular model of phonologic encoding.
4. Present information on the types of speech production errors produced by normal participants and individuals with aphasia.
5. Discuss the role of speaking rate in phonologic encoding.

2.0 REVIEW OF THE RELEVANT LITERATURE

2.1 MODELS

Several speech production models have guided the interpretation of speech error data in both normal and disordered speakers. These production models vary in their degree and level of explanation, types of processing (e.g., serial or parallel) and in the specific mechanisms (e.g., activation, feedback) proposed to account for the observed behaviors. Some models identify and characterize all levels of the production system (Garrett, 1980; Levelt, 1989), while others have a narrower focus and attempt explanation at only one level (e.g., Dell, 1986; Shattuck-Hufnagel, 1979). This discussion will begin with the presentation of these two general models of speech production, in order to provide a framework in which to view the level-specific phonologic encoding models.

2.1.1 Broadly Focused, Multilevel Models

2.1.1 Broadly Focused, Multilevel Models

Garrett (1980, 1984) developed an influential sentence production model that provides a framework of production processes from the conceptual to articulatory levels. It includes five levels of representation: (a) message, (b) functional, (c) positional, (d) phonetic, and (e) articulatory and offers an explanation for how sound-level production errors may be produced from a linguistic perspective. Production is driven by the intended message at the message level, which through various computations develops a form or syntax at the functional level for which lexical items are then chosen. The positional level is characterized by the retrieval of segmental structures, the specification of parameters for the frame that the segmental structures will fill, and the assignment of lexical items to their phrasal positions. Within this model, sound errors occur during the translation from the functional to the positional level. Examples of form-based word substitutions (i.e., 'shaving' for 'skating'), sound exchange errors, and "stranding" (Garrett, 1984, p. 177) exchange errors (e.g., 'paged the numbers' for 'numbered the pages') serve as evidence for processing operations at this level of production. Based on speech error data (e.g., word exchanges) Garrett (1984) conceives of the unit of planning at the functional level as multi-phrasal, but only a single phrase at the positional level. The model acknowledges a role for phrasal stress in the planning frame and posits that the articulatory level is necessary in the model because of evidence for phonetic errors. Additionally, Garrett (1980, 1984) makes the claim that if speech error data are used to inform normal processing structure, then the examination of these errors and their interactions should provide information about the computations or processing functions that occur at the different levels of the production system. While variables such as the role of stress and the size of planning frames are discussed to some degree, a lack of specificity in this model contributes to its inability to make predictions about interactions within the phonological and articulatory levels of the production system. The effects of speaking rate on phonologic encoding are not specified or addressed in this model.

Levelt (1989) developed a comprehensive speech production model that is similar to Garrett's (1980); however, it addresses multiple levels of the production system more extensively. Levelt's model provides specific details about many of the production levels and discusses in greater detail the transcoding of information from one level to the next, as well as the interactions of different processing levels. Levelt's model is best described as a stage model of speech production and in general, incorporates the characteristics of informational encapsulation, and unidirectional and incremental processing. This model contains three major components: The conceptualizer, the formulator and the articulator. However, the transcoding processes that occur as information moves from one major component to the next are critical to the explanatory power of the model. In general, production processes proceed from message conceptualization, to accessing the lemmas (i.e., lexical items) that are most relevant for expression of the intended concepts, to activation of the syntactic information relevant for those lemmas. Lemmas are the meanings or concepts related to a lexical item. At the conclusion of syntactic encoding, a surface structure has been developed and this information is transferred to the phonologic encoder. During the process of phonologic encoding, a phonetic or articulatory plan is developed that the articulator is able to use to produce overt speech. Of particular interest for this review are those processes that occur between phonological encoding and articulation; that is, those processes preceding movement execution for the purpose of producing speech.

Levelt (1989) identifies three major levels of processing within phonological encoding. They are: (a) morphological and metrical spellout (retrieval of morphological and metrical structure); (b) segmental spellout (accessing form information for a word); and (c) phonetic spellout (accessing stored phonetic plans). While production in this model is viewed as lexically driven, surface structure is an important product of grammatical encoding that is used as input to the phonological encoder. Relevant information included in the syntactic structure is information about morphology, phrasal properties, including correct syntactic order of elements, lexical categories of units (e.g., noun, preposition), pitch accent (e.g., intonation), mood (e.g., declarative, interrogative), and prosodic focus. The phonological encoder uses this information to develop a phonetic plan for the articulators. In Levelt's model, phonological encoding includes retrieving or accessing segments and generating phonetic plans. Levelt defines a phonetic plan as "a rhythmic (re-) syllabification of a string of segments" (1989, p. 284). It is developed from available lexical and surface structure information and consists of "the spelling out of stored form representations and their projection on pronounceable syllables" (p. 318). The phonetic plan is a post phonological encoding (i.e., retrieval or accessing of segments), pre-motor execution process, in which output is prepared for the articulatory buffer. The articulatory buffer is described as a storage space for phonetic plan information as it is readied for execution. This articulatory buffer is proposed because phonological encoding and availability of the phonetic plan are not seen as necessarily occurring with the same time-course as execution processes. Subsequent support for this perspective is provided by Roelofs (1997b) who, based on experimental evidence, identifies the phonological word as the minimal unit necessary for articulation to begin. Within this model, other parameters such as pitch, stress, and intensity must still be examined as well as changes that might be necessary to facilitate co-articulation (Levelt, et al., 1999). According to the model, when phonetic plans are combined to produce connected speech, the metrical and intonation parameters of the utterance change. These changes affect phonetic spell-out and result in syllabification and pitch changes. Furthermore, the initiation of articulation has been demonstrated to be characterized by latencies related to the size of the unit (e.g., phrasal level phonological words) to be produced (Wheeldon & Lahiri, 2002), providing support for the conceptualization of an articulatory buffer.

As previously stated, the phonetic plan develops from lexical and surface structure information and includes the morphological and phonological information about a word.

According to Levelt (1989), words are composed of syllables and syllables consist of "one or more slots that can contain phonetic material, such as consonants or vowels" (p. 290). Quality and prosody information such as feature (e.g., voiced vs. unvoiced) and metrical information (e.g., syllable duration) compose the phonetic content of the slots. Levelt conceives of this information as being distributed across five different tiers (i.e. skeletal/timing, syllable, segment, metrical and intonational). Some aspects of this model such assumptions about morphophonological encoding, are well specified and supported with experimental evidence (Meyer, 1990), while the phonologic encoding to articulation aspects of the model need further investigation (Levelt, et al., 1999). Despite the need for further testing, a noteworthy strength of the Levelt (1989) model is that the assumptions about the phonetic content of slots allow for hypotheses about how the phonologic and speech motor systems might interact.

While Garrett (1980) and Levelt (1989) developed production models for the entire production system, Shattuck-Hufnagel (1979; 1987) developed a model specific to the level of phonologic encoding. This scan-copier model of phonologic assembly is composed of a serial ordering mechanism that consists of two independent levels of representation: slots and units or segments to fill the slots. The model also contains monitoring devices that aid the "copier" in keeping track of which units have been copied, and in detecting errors. This model is compatible with many errors related to, or demonstrated in normal speech production. Shattuck-Hufnagel's model attempts to predict error types, account for some categorical constraints, explain why word onsets are particularly subject to error, and identifies factors that can influence error occurrence. However, it does not guide hypotheses about the effects of speaking rate on phonologic encoding process.

2.1.2 Narrowly Focused Models

Dell (1986) developed a speech production model of phonological encoding processes in the intact speech/language production system. While this model describes other levels of the production system, it is most completely specified at the level of phonological encoding. The model proposes the mechanism of bi-directional spreading activation, and emphasizes the excitatory characteristics of processing within this framework. Spreading activation and decay rates reflect the rate of processing and based on the general theory supporting the model, the rate of processing in the lexical network is assumed to be constant. Bi-directional spreading activation allows for feedback amongst levels, which is not a characteristic of the Levelt (1989) model. Similar to Levelt, however, incremental production processing is incorporated in this model, such that processing can proceed with only partial input from a previous production level. In general, production processes in this model are similar to those described by Levelt; however, the effect of the variable of speaking rate is made explicit within the Dell model.

Phonologic encoding is defined by Dell (1986) as the spelling out of the sounds of a morpheme. This spell-out includes retrieving, ordering and organizing phonemes for articulation. Dell uses speech error data to test assumptions about phonologic encoding processes. He examined three variables that can affect the production of sound errors. These effects included output biases, repeated-phoneme effects and speaking rate effects. An examination of these effects reveals the interactive nature of processing within the model. Lexical, syllable and frequency biases are the output biases examined by Dell. These reflect the effect of higher level processing (e.g., lexical) on sound production errors. An example of the lexical effect, the so-called lexicality effect, is the tendency for sound errors to result in words, rather than non-words. The repeated-phoneme effect is interpreted as accounting for errors of similarity, such that sounds that are more similar or that share features tend to induce errors and has been described as a contextual influence (Dell, 1986). Finally, the effect of speaking rate addresses “a trade-off between speed and accuracy of encoding” (Dell, 1986, p. 301) and predicts different error patterns for different speaking rates. Dell emphasized the importance of this effect because it provided a link between the mechanism and the behavior or interaction of the other effects. Unique to this model and specifically related to the temporal nature of spreading activation, are predictions regarding phonological encoding and the manipulation of processing time.

Wheeler and Touretzky (1997) posited a parallel licensing model of normal slips and phonemic paraphasias in which phonological encoding processes and phoneme selection are the product of specific linguistic-based constraints. The authors proposed that this parallel processing model was able to account for normal error slips as well as phonological paraphasias and additionally, has the specific advantage of accounting for the phonotactic well-formedness of speech production errors, as other models (e.g., Dell, 1986; Shattuck-Hufnagel, 1979) do not account for phonotactic constraints. In this model all units of a word or phrase must be “licensed” or organized by a prosodic category and certain units license other units. The authors suggest that the licensing operation contributes to phonotactic well-formedness because all units are connected to a higher constraining unit. Thus, a licensing hierarchy would place the phonological word at the top of a hierarchy with metrical feet subsumed below, followed by syllables and then segment units. The process of licensing is constrained by a set of Linear Order Constraints (LOCs). These LOCs control which units may be associated and operate based on the degree of lexical activation that has occurred when the licensing process begins. In this model simultaneous lexical retrieval of several words is assumed to occur and as a result, the licensing process may act on many units simultaneously. Segments may be licensed by multiple higher-level units and higher-level units may license multiple segments. If licensing operations begin before lexical activation has fully activated all features (underspecification), the LOCs may allow units to be inappropriately associated with other units. Multiple and simultaneous licensing along with underspecification allows for erred sound productions.

In this model, serial order is maintained with constraints placed on slot number, sonority, and maximal onset principles. Serial order errors result from licensing errors caused by underspecification. That is, order errors (i.e., anticipations, perseverations, exchange errors), occur when a unit has been inappropriately licensed by more than one constituent at the same time and are the direct result of underspecification. Exchange errors in particular, occur as a result of multiple licensing, underspecified LOCs and the simultaneity of the licensing process. The authors assert that more speech production errors will occur at fast speech rates because at fast rates more units are available to be licensed and underspecification is more likely to occur. Other than the general prediction that more errors should occur at faster speaking rates, this model makes no predictions regarding the effect of speaking rate on specific serial order sound production errors. Support for the assumptions of the parallel licensing model is provided by a computer simulation that encoded a short (two word) phrase. The authors varied parameters of feature activation (not speaking rate or processing time) and obtained different proportions of serial order errors with manipulation of this variable as evidenced by the raw data counts. Though no statistical analyses are provided, the authors state that the computer simulation data produce error types and proportions similar to those reported in normal and aphasic speech production. While the assumptions of this model are theoretically based and perhaps account for some aspects of production errors that other models do not, it does not account for aspects of production errors that are addressed in other models (i.e., lexical effects, distance effects). Additionally, support for this model has only been demonstrated through simulations and no human experimental evidence has been provided.

In contrast to frame based models like Dell (1986), Shattuck-Hufnagel (1979), and Wheeler and Touretzky (1997), Vousden, Brown and Harley (2000) proposed a control-signal based serial order model of phonology. In this model, phonological encoding begins when form information is retrieved from the mental lexicon. Form information and metrical structure must merge and phonemes become associated with the metrical structure that results after re-syllabification processes. In this model phonemes do not become associated with slots in a frame. Instead, they become associated with a particular state in an "intrinsically dynamic control signal" (Vousden, et al., 2000, p. 126) called the "phonological-context signal" (Vousden, et al., 2000, p. 126), which encodes and maintains phoneme order. Successive syllables and phonemes are activated because they are associated with temporally adjacent parts of the time-varying signal, thus eliminating the need for position specific coding for phonemes as implemented in Dell (1986). As the state of the signal changes the phoneme associated with that part of the signal becomes activated, thus the phoneme with the most activation at a particular time becomes selected. The phonological-context signal is controlled by an assumed set of repeating and non-repeating oscillators that have different frequencies and initiate the signal. Phonemes are assumed to become associated with different states of the changing phonological-context signal during planning processes. Both serial order errors and non-contextual errors result from noise in the system. Post-output suppression is used as the turn-off mechanism once a phoneme has been activated so that the next phoneme may be selected. The likelihood of an anticipation or perseveration error is directly linked to post-output suppression and favors anticipatory opportunities. According to the model, once a phoneme has been turned off by post-output suppression, it would need further activation to be re-selected again at a later time. However, in the case of anticipations, a sound that gets selected in advance of its target location will similarly be suppressed by post-output suppression but the sound is easily selected again because there is a further source of activation generated by the accurate target position. Exchange errors occur when the activation level of the sound replaced by the anticipation error, and thus not selected and subject to post-output suppression, is higher than the activation level of the correct target location of the unit involved in the anticipation error. While the model makes no predictions about the role of speaking rate, speaking rate effects might be explored by varying the time parameters of the aforementioned oscillators. The authors report that the Oscillator-Based Associative Recall (OSCAR) model is able to produce the same rate effects as in Dell (1986) and Dell, et al. (1997), by varying the amount of time between successive phonemes. At fast speaking rates post-selection inhibition is less effective because the "states of the phonological-context signal" (Vousden, et al., 2000, p. 157) are more alike than at slower speaking rates.

Vousden, et al. (2000) assert that a central advantage of their model over other phonological encoding models is the inclusion of a mechanism that controls serial order for both the frame and segments without the need for a frame and positional cues as described in Dell (1986). Additionally, the proposed mechanism is independently motivated and is not included as a post-hoc addition simply used to explain the data. The authors state that the motivation for the dynamic time-varying phonologic-context signal stems from oscillator systems that are found in human movement and studies on short term memory. Other primary differences between this model and others discussed in this review are the lack of an explicit hierarchical frame and the elimination of the need for a serial order buffer. Acknowledged limitations of this model include its inability to address lexical effects and findings regarding phonotactic well-formedness (Vousden, et al.).

2.1.3 Comparison of Models

Of the models discussed thus far, the Levelt (1989) and Dell (1986) models and their subsequent iterations have predominated the discussion of speech production phenomena. Both models have been further developed through model testing and with the accrual of experimental data following their initial publication. It should be noted that while these models predominate relative to lexical/phonological speech production processes, the authors of both models acknowledge the contributions of the Garrett (1980, 1984) and Shattuck-Hufnagel (1979, 1983, 1987) models.

As predominant competing speech production models at pre-motor levels of processing, it is relevant to compare the models on their basic assumptions. The explanatory power of any production model, general or level specific, is directly tied to the assumptions and processing characteristics of that model. Rapp and Goldrick (2000) examined several production models relative to the presence, degree and role of interactivity within each. As part of this effort, they examined the role and evidence for cascading activation, feedback, the domains of interactivity ("the number and types of processes that are assumed to interact," p. 462), and seriality ("the degree to which there are processing steps or decision points between input and output," p. 462) within each model, as these are described as mechanisms of interactivity. The models of Levelt (1989,1992) and Dell (1986), as well as subsequent, further developed iterations of those models by those investigators and their colleagues (e.g., Dell, 1988; Dell, Schwartz, Martin, Saffran &

Gagnon, 1997; Roelofs, 1997b) are two of the model frameworks evaluated in the Rapp and Goldrick discussion. Their goal was to determine how the aforementioned features interact with and affect spoken word production.

Rapp and Goldrick (2000) developed five categorizations of theories to capture the discreteness-interactivity dimension across the models of interest. The theories were categorized as one of the following: (a) Discrete feedforward account (DFA), (b) Cascading feedforward account (CFA), (c) Restricted interaction account (RIA), (d) High interaction account (HIA), and the (e) Further interact, low seriality account (FILSA). Of particular interest for this discussion are the models of Levelt (1989) and colleagues (Levelt, et al., 1999), examples of a discrete model; and Dell (1986), an example of an interactive model. The evaluation of the models was primarily based on the ability of the model to account for lexical bias (the tendency for an error to result in a word rather than a non-word) and mixed-errors (i.e., semantic and phonologic related errors) effects. These errors are important because as Rapp and Goldrick stated, a review of the literature reveals repeated evidence for these effects in both non-brain-damaged (NBD) persons and PWA. It should be noted, however, that while some investigations have revealed support for the lexical bias effect (e.g., Dell, 1986; Dell & Reich, 1981; Martin, Dell, Saffran & Schwartz, 1994) conflicting results have been reported by others (Nickels & Howard, 1995). Additionally, evidence from at least one other study (Baars, Motley and MacKay, 1975) has shown that the presence of lexical bias can be affected by experimental conditions such as the word/non-word status of target and filler stimulus items giving concern for the ubiquity of this effect.

According to Rapp & Goldrick (2000), the mechanisms of cascading activation and feedback are important because they allow activation from the target and its neighbors at one level, to affect units at another level and make non-target units relevant throughout processing. Models incorporating these mechanisms can account for the lexical bias and mixed-error effects as semantic and phonologic activation is simultaneously active throughout the system and can influence production outcome. The DFA account restricts processing by stage and does not allow for feedback. The CFA account allows concurrent processing stage effects but does not allow for feedback. Rapp and Goldrick proposed that while cascading activation is not viewed as necessary to obtain the lexical bias effect, feedback is necessary. As such, the highly discrete system would predict that with phoneme selection or encoding errors, the probability of whether or not an error resulted in a word or nonword should be at chance levels. They report that a review of the speech error literature which examined the lexical bias effect, as related to assumed phoneme level disruption, reveals that the effect occurs at greater than chance level. Roelofs (2004) challenges their position with an alternative perspective that appeals to a self-monitoring/comprehension account of production planning processes, as well as other factors, which allow for lexical bias effects without the need for feedback. Similarly, Levelt, et al. (1999) acknowledge the lexical bias effect; however, attribute the effect to indirect feedback of the phonetic plan to the comprehension system. Motley, Camden and Baars (1982) have also presented data that they argue can be explained by either feedback or an editing mechanism. These findings call into question a dismissal of DFA and CFA models on the issue of lexical bias. However, Rapp and Goldrick's interpretation of these data is supported by the theoretical perspective of Dell (1986) and by experimental evidence from many other investigators (Baars, Motley, & MacKay, 1975; Gagnon, Schwartz, Martin, Dell, & Saffran, 1997), though contrasting findings do exist (Schwartz, et al., 1994). It is suggested by Rapp and Goldrick that the prearticulatory/postencoding editor proposed by some models is unsatisfactory because it would necessitate redundancy of information within the production system. With this interpretation and using computer simulation data, the authors concluded that the inability of the DFA (i.e., Levelt, et al., 1999) and CFA models to explain the lexical bias effect is problematic for them.

Rapp and Goldrick (2000), further argue for a similar weakness of DFA models to explain the frequently obtained result of more mixed-errors (a word substitution that is phonologically and semantically related to the target) than one would expect by chance. They also argue that interactive models are better able to account for both the lexical bias and mixed-error effects because they include cascading activation and feedback, thus allowing for interaction between the semantic and phonological levels. Roelofs (2004) argues that based on the evidence that Rapp and Goldrick (2000) and Levelt, et al. (1999) provided, the mixed-error effect is the influence of semantics on phonology and thus feedback is not necessary to explain it. Additionally, a faulty self-monitoring system is able to account for this effect.

To further distinguish the role of interactivity among the interactive accounts, Rapp and Goldrick (2000) provide data from three case studies of neurologically impaired individuals and use computer simulations to evaluate the interactive models' ability to account for the speech production behaviors exhibited by these individuals. The computer simulations are designed to create the error patterns exhibited in the case studies and each incorporated assumptions from one of the three interactive accounts. Relative to the role of cascading activation and feedback, simulation results supported both the RIA and HIA. Though the RIA account was sufficient, the HIA account was also able to recreate the error patterns with some caveats. It is not clear whether the authors considered the Dell (1986) model to be included in the RIA or HIA account. It is clear, however, from their narrowly focused evaluation of these models, that the assumptions of the Dell (1986) model are consistent with the empirical findings of the demonstrated lexical bias and mixed error effects in spoken word production. For the current investigation this evaluation of the predominant competing pre-motor speech production models and evidence related to their basic processing assumptions lends support to the use of the Dell model (1986) and its subsequent iterations to examine the effect of relevant variables on phonological encoding processes and serial order, sound-level errors, in pathological states such as aphasia.

The models discussed have primarily focused on a general explanation of the entire production system or have primarily addressed the level of phonologic encoding, all from a linguistic or psycholinguistic perspective. Before a more in-depth examination of the issue of phonologic encoding is undertaken, a production framework will be discussed which focuses on post-phonologic processing from a neurophysiological perspective. This framework is discussed to provide a further context in which to view the speech production processes, as in the current study inferences about phonological encoding will be based on overtly produced speech resulting from a task in which the required manipulation potentially affects motor as well as phonological processing. Sound-level changes that occur that may not be attributed to phonological-level processing should have some basis for interpretation. Support for error categorization and assigned level of processing may be further substantiated by a conceptual framework focused at other relevant levels of the production system which are not addressed or not addressed to any substantive and testable way by the predominant phonological encoding models.

2.1.4 A Model for Impaired Production Systems

Van der Merwe (1997) developed a theoretical framework for characterizing the speech production processes using pathological speech production. This model emphasizes sensorimotor control and the integration of sensory and motor processes. This 4-stage model divides the production system into the linguistic-symbolic planning, motor planning, motor programming and execution levels of production. Thus, much of the substance of the models discussed above is subsumed within the first division of this model. Van der Merwe attempts to provide greater specification to those processes that occur after lexical access and phonological encoding. Motor planning processes include specification of motor goals, determining the movements that will be necessary to accomplish those goals and determining the order in which they need to occur. This framework posits how motor goals are specified and how a motor program then uses this information to prepare the muscles of the sensorimotor system for movement.

Though acknowledging that there has been debate over the concept of motor programming, Van der Merwe (1997) uses the idea of a motor program to describe those processes that follow motor planning processes, but which occur before and are not a part of the execution levels of the speech production process. In this framework, a motor program includes the use of sensory and internal feedback and it involves selecting and sequencing "motor programs of the muscles of articulation" and "specification of the muscle-specific programs in terms of spatiotemporal and force dimensions such as muscle tone, rate, direction, and range of movements" (Van der Merwe, 1997, p. 16). According to her, impairment at the motor programming level of this framework would result in the production of sound distortions, and deficits in movement initiation and speech rate. Thus, Van der Merwe's framework assumes that disruption at the level of motor programming results in movement level deficits. Other investigators of speech and motor deficits concur with this perspective (Ogar, et al., 2006; Schirmer, 2004).

The fourth level of processing in this speech production model is the execution level and it is the realization of the motor plan and program processes. Phonological encoding processes have been completed before this level of processing addresses that particular target. As with the other levels of processing, it is posited that specific speech characteristics should result from impaired functioning at this level. The motor planning, motor programming and execution levels of processing will not be directly addressed in this review as the focus of this investigation is on the process of phonologic encoding. As previously stated, it is assumed that the speech production errors produced in the individuals with aphasia are due to disturbed processing at the level of phonologic encoding. It is acknowledged, however, that disruptions at the motor planning, programming and execution levels of the production system may result in production errors (i.e., disturbed speech prosody, timing, distortion errors) as well.

This review will focus on the phonologic encoding models of Dell (1986) and colleagues because they provide testable hypotheses and because they make specific predictions regarding the effects of speaking rate. While Vousden, et al. (2000) did not make specific predictions regarding speaking rate, their simulation data support the assertions and data from the Dell (1986) and Dell, et al. (1997) models. Additionally, Dell's (1986) conceptual framework has been theoretically and experimentally extended to aspects of semantic and phonological performance in individuals with aphasia (Schwartz, et al., 1994; Dell, et al., 1997). Despite the focus on the Dell (1986) model and despite the fact that there are important differences between the Dell (1986) and Levelt (1989) models, the process of phonological encoding is placed within the more general model of Levelt to provide a framework for the full speech production process. Levelt's model provides the framework because it is a comprehensive model that describes the speech production process from the conceptual level to articulation. While motor level processing is an underdeveloped part of the Levelt model, the model attempts to explain how the phonologic system might affect the motor system. One consideration throughout the Levelt model is the type of input necessary for the following processing stage. According to Levelt a major goal of the phonologic encoding process is to produce a string of syllables that the articulators are able to pronounce. The mental syllabary, a mechanism postulated by Levelt (1992) and Levelt and Wheeldon (1994), is conceived of as "a mechanism for translating an abstract phonological representation of an utterance into a context-dependent phonetic representation which is detailed enough to guide articulation" (Levelt & Wheeldon, 1994, p. 240). The descriptions of the processing steps that are necessary to accomplish the goal of phonologic encoding provide insight into the variables important for the interaction of the phonologic and motor levels of encoding. Van der Merwe's (1997) model is incorporated in this discussion to provide a framework for those processes that occur at the post phonologic stage of production, the part of the model that is under specified in Levelt (1989). The detailed description of the processes that occur at the motor planning and motor programming levels provided by Van der Merwe and the specificity of the Levelt (1989) and Dell (1986) models, provide a focused framework from which to discuss the phonologic to pre-articulatory continuum. This review of several speech production models with a focus on phonological encoding has acknowledged their different theoretical perspectives, proposed mechanisms, structural and processing differences, and highlighted their strengths and weaknesses. While the combination of these models are not the only viable accounts of speech production (e.g., Guenther, 1995) they uniquely discuss the effects of speech rate (to differing degrees) on the various processes relevant to sound-level speech errors; the focus of this investigation. Importantly, none besides Dell (1986) and Dell and colleagues (Dell, et al., 1997) make specific predictions regarding the effects of the manipulation of speaking rate. Furthermore, none present constructs that would argue against his predictions and the very preliminary findings that support it.

2.2 PHONOLOGICAL ENCODING

Phonological encoding is a process that involves several different stages (Dell, 1986; Garrett, 1980; Levelt, 1989; Levelt & Wheeldon, 1994; Shattuck-Hufnagel, 1979). The term stages as used here, is meant to convey the idea of different components of the process, not necessarily discrete levels of processing. Though the term may be interpreted in more than one way, it is used here because it is used by proponents of the discussed relevant theoretical perspectives as well others (i.e., Rogers & Storkel, 1999). As described by Levelt and Wheeldon (1994), these stages include: (a) the activation of the word's form information, (b) an association of segments to the word's frame and, (c) accessing articulatory scores in the mental syllabary. Activation of the word's form information involves two types of information: content and metrical form information. Content information consists of the segments that compose the word. Levelt and Wheeldon conceive of segments as fully specified phonemic structures (i.e., consonant and vowel units) in the same way as Dell and Shattuck-Hufnagel. Metrical information or information about the word's frame consists of information about the number of syllables in the word and the stress levels of the syllables in the word. Levelt and Wheeldon stated that information about the consonant-vowel (CV) structure of the syllables in the word, the special status of word onset, syllable weight (internal organization of word stress) and the degree of reduction of syllables are other aspects of metrical information that may be available, a notion posited in various theories. In the second stage of phonological encoding, a mechanism is proposed that connects segmental (form) information with word frame (metrical) information. Levelt and Wheeldon refer to this process as phonological word formation. The third stage of phonological encoding as posited by Levelt and Wheeldon addresses how abstract phonological representations are transferred into a code usable by the articulatory system. For Levelt and Wheeldon, this process is addressed by accessing the mental syllabary (to be discussed in detail). Investigators have posited different perspectives on how the phonologic encoding process proceeds at each stage.

2.2.1 Frame Representation

Two-stage models of lexical retrieval posit that lexical access consists of two parts (Levelt, 1992). The first part is activation of semantic and syntactic information or lemma retrieval and the second part is access of word form information or lexeme retrieval. Lemma activation will not be addressed other than to specify that it involves lexical retrieval and grammatical encoding. Additional discussion of this level is beyond the immediate scope of this study. As proposed by Shattuck-Hufnagel (1979), word form (lexeme) information includes two independent types of information. The idea that word form information consists of a frame for the word and the elements or segments that will fill that frame is accepted and included in many speech production models (Dell, 1986, 1988; Levelt, 1989, Shattuck-Hufnagel, 1979). Research regarding the frame has addressed what information is included in the frame (Levelt, 1989), how it is structured (Dell, 1986; Dell, 1988; Levelt, 1989; Roelofs, 1997a) and how serial order is maintained in the frame (Vousden, et al., 2000). One issue of debate among investigators has been whether word or syllable structure (CV) is stored in the lexicon.

Dell (1988) proposed that syllable structure for a word is stored in the mental lexicon, while others propose that syllable structure is realized when a word becomes part of an utterance (Levelt & Wheeldon, 1994; Roelofs, 1997a). More recent investigations (Vousden, et al., 2000) of phonological encoding have incorporated the perspective advanced by Levelt and Wheeldon (1994) and Roelofs (1997a) as the Dell (1988) perspective is unable to account for the re-syllabification that naturally occurs in connected speech (Roelofs, 1997a). In Dell (1986) the basic phonological representation is characterized by the CVC structure. The model accounts for the phonological representation of words that do not follow this structure by including null and cluster elements. Dell (1988) proposes this concept of CVC structure by incorporating in the model, word-shape nodes that represent multiple CVC combinations in one and two-syllable words. According to Dell (1988) the motivation for this proposal was the inability of the previous version of the model to explain the occurrence of sound additions and deletions. Dell (1988) acknowledged, however, that allowing for multiple word-shapes produced the potential unexplored issue of whether or not there was competition among the various word-shapes and the potential consequences of such competition.

Sevald, Dell and Cole (1995) conducted a study to examine whether syllables are represented in speech production plans and if so, how syllable structure is represented. This study compared two opposing views of how word forms are stored. One perspective proposes that the sounds and syllables of a word are stored as a unit or as a chunk. The opposing perspective, the schema view, proposes that only the frame of a syllable is stored and sounds are inserted into the frame. It is suggested that the frame only indicates the number of sounds in the syllable and perhaps whether the sounds are consonants or vowels. In several experiments, Sevald, et al. (1995) manipulated the syllable boundaries in mono- and di-syllabic word pairs and the sharing of content (specific consonants and vowels) and syllable structure in word pairs (i.e., CVC CVC.CVC vs. CVCC CVC.CVC) in word pairs. Participants were asked to repeat phonological word pairs, without making errors, as many times as possible in a specified time frame, which either did or did not share content and or structure. Planned contrasts controlled for the word length effects resulting from different CV structures. It was hypothesized that faster production times in any shared conditions would serve as evidence that the shared parameter was represented in speech planning at the abstract level of phonological encoding. Results, based on all 3 experiments, revealed that repeated CV structure yielded faster production times and supported a schema structure for syllables. Sharing content added nothing to the effect. The authors interpreted their results as evidence for schema models. Roelofs (1997a) criticized this interpretation by arguing that because Sevald et al. measured the number of targets the participants were able to produce within a specified time period, one could not be certain as to whether the effect of CV structure had arisen during the creation of the phonological representation or during the retrieval or execution of motor programs. As will be seen in later discussion, Levelt and Wheeldon (1994) propose that there is a repository for stored syllabic gestural scores. That theoretical perspective would suggest that Roelofs' criticism, at least as related to retrieval, has merit, as changes in structure or content would necessitate accessing different stored syllabic gestural scores.

Meijer (1996) also investigated whether or not CV structure is stored**.** He compared assumption from different iterations of the Dell model (1986, 1988), relative to the storage of CVC structure. Specifically, the first of three experiments investigated whether consonant clusters were represented with one or more slots. In a translation task, similar to the experiment conducted in Sevald et al. (1995), Meijer manipulated whether target and primes either were similar or different in onset and CV structure, as well as the stimulus onset asynchrony (SOA) of the primes. SOA was manipulated to determine whether structural information was retrieved in a different time course than phonemic content. The results from this study supported independently stored and retrieved CV structures, as participants produced significantly fewer errors and production latencies were significantly faster in the shared CV structure condition. As in the Sevald et al. study, shared onset between target and prime did not yield significant results. Meijer interpreted his results to suggest that there is a structure retrieval process that chooses a CV structure from a set of possible CV structures. That is, consonant clusters were represented for each segment and not as one consonant structure. In the second reported experiment, primes and targets either had the same CV structure or completely different CV structures. The results relevant for this discussion revealed that in contrast with experiment 1, significantly lower error rates were not obtained in the shared CV structure condition. Similar to experiment 1, however, significantly faster reaction times were obtained. In general, the results of the second experiment replicated the findings of the first experiment providing supporting evidence that CV structure is stored and that different structures are retrieved depending on CV order and the presence or absence of clusters. A third experiment, still using the translation naming paradigm, examined whether or not a slot in a structure condition corresponded to only one phoneme or whether a phoneme could be related to more than one slot (i.e., a long vowel). Stimuli either shared onset and did or did not share vowel length or did not share onset and did or did not share vowel length. Reaction time results revealed no significant effects of vowel length suggesting that each vowel, short or long occupies only one slot in the CVC structure. Overall, results from all three experiments were interpreted as supporting evidence that CVC structure (as conceived in Dell, 1988) is stored and retrieved during word form encoding. The significance of these findings relative to the current investigation is that they provide supportive evidence for the validity of the Dell models (1986, 1988).

Despite these findings, Roelofs (1997a) argues that there is little empirical support for the stored syllable structure and asserts that a weakness of the stored syllable structure perspective is that it does not allow for syllabification across morpheme boundaries, as might occur with a phonological word. Roelofs provides the Dutch word ‘juwelen’ as an example. ‘Juwelen’ is the plural form of the word ‘juweel.’ In the singular form, the /l/ in ‘juweel’ occupies a coda position, however when changed to the plural form the word is syllabified differently and the /l/ now occupies an onset position. Roelofs states that Dell’s (1986) model would represent the plural form of the target word with a node for the stem (‘juweel’) and another for the plural suffix. As the /l/ is marked for a final consonant or coda position in the singular form, Roelofs argues that the Dell model cannot explain how the /l/ can be selected for the onset of the third syllable in the plural form of the word when the syllabification changes. This appears to be a valid criticism of one conceptual aspect of Dell’s model. Dell’s model might be able to address this criticism by incorporating a post-phonological encoding, pre-motor editing mechanism that would compare retrieved CVC structure with prosodic and metrical information, however, these aspects of the speech production process were not addressed in Dell’s models (1986, 1998).

Roelofs and Meyer (1998) conducted a study to examine the role of metrical structure in spoken word planning. They sought to determine, whether metrical structure information was necessary for production planning, based on assumptions regarding the metrical frame as postulated in the Word-form Encoding by Activation and Verification (WEAVER) model proposed by Roelofs (1997b). Additionally, if it was determined that metrical structure information was necessary; they sought to determine which aspects of it were necessary. In

WEAVER, a metrical structure is characterized as “an abstract grouping of syllables” (p. 925) that forms a phonological word. Primary stress is marked on the relevant syllable. The serial positions of phonemes within the morpheme are specified by links between the morpheme and segment nodes. Links between segment and syllable program nodes (i.e., mental syllabary) specify the possible syllable positions of the segments. CV structure is not represented in the WEAVER model. Based on the WEAVER model, it was predicted that facilitation (shorter production latencies) should occur when participants are able to prepare and buffer partial shared representations before a response is prompted. Evidence for facilitation was demonstrated in investigations by Meyer (1990, 1991) that revealed priming or facilitation when sets of response words contained homogenous (share one or more initial segments) as opposed to heterogeneous onsets. Roelofs and Meyer stated that “WEAVER predicts that facilitation should be obtained only if the response words in homogenous sets share segments and have the same metrical structure” (p. 927). They assert that if the number of syllables and the stress pattern of words in the response set are variable this effect of facilitation would not be demonstrated. However, “if metrical structures are not involved in advance planning or if they are computed on-line on the basis of the retrieved segments,” a facilitation effect should be demonstrated with even with a varying number of syllables and stress pattern (p. 927). The suggestion here seems to be that if metrical structures are not relevant or if their value is tied to the segments that are retrieved, then the numbers of syllables and the stress patterns should not matter, as they are assumed to be information contained in the metrical structure. Furthermore, as WEAVER does not code CV structure, Roelofs and Meyer predict that facilitation should occur with shared segments regardless of whether or not CV structure is shared among words in the response set.

Roelofs and Meyer (1998) examined the predictions about preparation with shared segments and metrical structure in several experiments. They manipulated the homogeneity (i.e., shared first syllable, shared onset) of the response sets, the specific shared syllable fragment, the consistency of the number of syllables in a response word set (a response set could be composed of words all containing two syllables or it could be composed of two, three and four syllable response words), shared CV structure and/or the consistency of the stress pattern in the response set words. Using the implicit-form priming paradigm and supporting the predictions of WEAVER, a main finding revealed that a significant preparation effect was obtained when words in a response set shared the initial syllable (segmental overlap) compared to when there was no segmental overlap and when the response set contained a constant as opposed to variable number of syllables. Error percentages and production latencies for correct responses were the dependent variables. Errors were characterized by incorrect response words, disfluencies, erroneous activation of the voice key by extraneous noises, or failure to respond with a specified time period after the signal to speak. There were no significant main effects or interactions for error data in any experimental conditions. Roelofs and Meyer conducted additional experiments to determine the role of stress in metrical information and to determine if a constant CV structure added to the preparatory effects obtained with shared segment and syllable number. The results revealed that the position of stress (second syllable or third syllable) in response words affected whether or not a significant facilitation effect was obtained across the various conditions. In general, a significant preparation (facilitation) effect was obtained for response sets in which the stress patterns remained constant. These results provided evidence that metrical structure contributes to the phonological preparation of an utterance. No added benefit of a constant CV structure was demonstrated. These experiments using chronometric as opposed to speech error data, addressed the general issue of what gets retrieved during the process of phonologic encoding. The obtained results argue against Dell's (1986, 1988) assumptions regarding the storage and retrieval of CV structures. Dell's models do not provide specification on the representation and integration of metrical information as a part of the phonologic encoding process. It is unclear what the implications of no CV structure would be within Dell's model (1986, 1988) relative to the spread of activation and role of feedback within the speech production system. Additionally, if CV structure is not stored, the role of structural constraints in Dell's model would need to be redefined as well as what and how phoneme selection is controlled. The results from Roelofs and Meyer suggest that further investigation of the nature of metrical frame information in word form encoding is necessary to understand its' role in phonologic encoding.

2.2.2 Content Representation – Features and Phonemes

In addition to the structure or frame information necessary for word form encoding, content information also must be accessed. Most speech production models posit the phoneme to be the unit of information that fills the metrical frame (Dell, 1986, 1988; Levelt, 1989; Shattuck-Hufnagel, 1979; 1987). Other notions of the unit exist, however, as some investigators conceive of an underspecified phonological representation in which all information about a phoneme is not automatically available, but is constructed from a set of default rules (Kohn, Smith, & Alexander, 1996). From this perspective, for example, non-contrastive information is unspecified (Dinnsen, 1997). According to Kohn and Smith (1995), "the basic tenet upon which all versions of Underspecification Theory rest (is) that the initial phonological description of a word is incomplete, and that a system of phonemic planning supplies the missing information"

(p. 210). Roelofs (1999), while not supportive of Underspecification Theory, summarizes this perspective by stating that in Underspecification Theory, the phoneme is represented by its features, is not an independently manipulated unit, and can be viewed as an emergent property of a combination of features. In Underspecification Theory, allophonic information is not included in the underlying representation. Thus, this theoretical perspective may provide a viable explanation for phoneme sound substitution errors (errors in which a good exemplar of a target sound is replaced with a good exemplar of another sound), however, it is not clear how it can provide a viable explanation for serial order speech production errors. While the basic premise of Underspecification Theory is accepted by its proponents, there is no uniform perspective regarding that which is or is not specified (Lahiri, 2000).

Shattuck-Hufnagel and Klatt (1979) examined the role of features in a large sample of spontaneous speech errors, produced by normal, non-pathological individuals. Based on an examination of a confusion matrix composed of single segment targets and intrusions, these investigators concluded that sound segment errors typically result from full segment errors and not from feature errors. Feature errors can occur, but did so with such rarity that the investigators concluded that errors are best characterized as segment errors and not feature errors (but see Rogers & Storkel, 1998 for a different perspective).

From a similar perspective, Roelofs (1999) designed several experiments that used the form-preparation paradigm developed by Meyer (1991) to investigate the role of features and segments as planning units in speech production. According to Roelofs, “phonological segments have their own abstract representation in memory, which is manipulated in planning utterances independent of their features” (Roelofs, 1999, p. 174). From this perspective, a segment is a chunk that “recodes a set of features into a representation that refers to the features but that does not contain the features as a proper part" (Roelofs, 1999, p. 174). So, while features contribute to a phoneme's identity, a phoneme is not just a combination of features. In this form-preparation paradigm, participants first learn a small set of word pairs and then, upon visual presentation of the first word, they produce the second. Word pair sets are either homogenous or heterogeneous, such that words in a pair either do or do not share part of their form (e.g., phoneme onset). The purpose of these experiments was to determine whether the initial segments of the response set needed to share all or only some of their features for a preparatory effect (as evidenced by shorter response latencies) to be demonstrated. Participants were presented with both homogenous and heterogeneous sets of word pairs. For the homogeneous word pairs, half of the word pairs shared fully the first segment and in the other half of the word pairs, the initial segments shared all but one feature. Voicing was the feature that was not shared among members of the response set in three of the four experiments. To determine if the results of the experiment were due to the voicing feature, in a fourth experiment the unshared feature was place. Response set words in the heterogeneous context shared no features. It was hypothesized that the segment similarity condition (a shared phoneme segment) would produce facilitation and that the similar features condition (all but one feature of a segment shared) would not. Results revealed significantly faster production latencies for the condition in which the initial segment was fully shared, but not for the other conditions. Other experiments manipulated the number of syllables in response set words or changed the task to picture naming, but results from all experiments revealed that only conditions in which all features were shared yielded enhanced preparation effects (i.e., shorter production latencies). Roelofs suggests that these findings may be due to the way in which features and segments are activated. He acknowledged that these results do not support the conclusion that features play no role in phonological encoding, but they do provide further evidence that the phoneme segment is a primary unit of planning at the level of phonologic encoding.

Evidence that features do have a role in phonological encoding is demonstrated in the phonological similarity effect (PSE). The PSE is defined as poorer performance on a task when the items to be recalled are phonologically similar to one another and has typically been identified in immediate verbal memory tasks (Baddeley, Lewis, & Vallar, 1984). Baddeley (1986) attributes this effect to the phonological store component of the phonological loop in his working memory model and proposes that the effect results from the fact that more similar items have fewer features to distinguish them and thus are more easily forgotten. This construct has been used to further explore the units involved in phonological encoding by Rogers and Storkel (1998). While these investigators refer to features in this study as "articulatory phonetic features" (p. 259), Lahiri (2000) asserts that features represent "a class of segments" (p. 175). According to this researcher, "phonological features are abstract entities with both acoustic and articulatory correlates" (p. 175). However, Rogers and Storkel use the term "phonetic." In a study with non-brain damaged participants, Rogers and Storkel used the PSE to examine the hypothesis that phonetic features play a role during pre-motor speech production encoding processes. An additional goal of the study was to determine which of three proposed mechanisms (i.e., editing, post-selection inhibition, simple replacement) is involved in reprogramming the phonologic buffer, a temporary processing space used during phonologic encoding. Rogers & Storkel defined speech programming as the stage when "the lexeme is translated into a speech motor code" (p. 259). They predicted that if the editing mechanism is involved in reprogramming the buffer faster response times should be seen for successive words in the experimental conditions as only unshared elements need to be reprogrammed. However if post-selection inhibition is the involved mechanism, response times should be slower as shared elements undergo inhibition before they can be re-selected. If reprogramming does not involve the sharing of any elements then simple replacement is the mechanism reprogramming the phonologic buffer. The simple replacement mechanism does not result in faster or slower response times as the buffer is completely cleared and new elements are programmed. Thus, though inhibition occurs, it has no cost effects because no elements are re-selected. This study incorporated the assumption that word frames are built and segment to frame associations occur within the phonologic buffer.

As previously described, each of the three mechanisms that are proposed to have a role during reprogramming operations predict different effects of phonological similarity. In this study it was assumed that phonologic similarity results from sharing articulatory phonetic features. The effects of phonologic similarity were measured by the dependent variable of the transformed speech onset latency (TSOL). Speech onset latency (SOL) is defined as the time difference between onset of the stimulus item and the voice onset time of a correct response. The number and identity of shared features (i.e., shared voicing, manner and place, etc.) in a form-based priming paradigm was manipulated. Young to middle aged adults produced phonologically similar, or dissimilar, prime-target word pairs, as quickly as possible. Stimuli were monosyllabic words that were visually presented on a computer monitor. Other independent variables that were manipulated included the stimulus set size, the inter stimulus interval (ISI) and feedback (regarding response times). A prime was presented a varying number of times before the target was presented. Erred productions, defined as continued production of the prime word, were not included in the analyses**.** SOL values were transformed by using a participant's early repetitions for each token and calculating the median SOL. Each of these median SOLs was then “subtracted from each individual SOL for that same token when it was produced by the same participant as a critical novel response” (Rogers & Storkel, 1988, p. 267). According to the authors, this transformed SOL (TSOL) was calculated to control for token and intersubject variability. Results were presented that describe the accuracy of responding as well as response time latencies.

Rogers and Storkel (1988) reported that for the experiments in which feedback was provided, the highest percentage of errors for response accuracy data occurred in the condition in which place and manner were shared and the lowest percentage of errors were produced in the control condition. Errors were primarily characterized by perseverative responses (erroneous repetition of a previously presented word). These descriptive findings suggest that more phonologically similar phonemes may disturb or negatively affect non-pathological pre-motor encoding. Latency data for the featural similarity conditions revealed significant differences from the control condition when voicing and manner or manner only were shared. Conditions in which feedback was provided and voicing and manner were shared or only manner was shared produced significantly longer TSOLs than the control condition. It was determined that shared manner contributed most to the observed inhibitory effects of phonologic similarity in these speech production tasks. Longer latencies in a feature sharing condition provide support for the role of post-selection inhibition in reprogramming of the phonologic buffer and were interpreted as such by Rogers and Storkel, (1998). Additionally, simple replacement characterized reprogramming of the phonologic buffer when no features were shared (the control condition). Rogers and Storkel had proposed that the mechanism of post-selection inhibition would result in delayed processing or longer SOLs because activation levels for re-selected units had to first undergo inhibition. Activation in utterances that shared no features would begin reprogramming with units that were already at resting levels of activation and thus would not be slowed. This was demonstrated in the control condition in which results supported a mechanism of simple replacement.

While other results addressing set size and ISI were obtained (and where relevant provided further support for the presence of the mechanism of post-selection inhibition), the most relevant finding for the current discussion is related to the role of feedback in investigating pre-motor processing. In experiments in which the presence or absence of feedback was manipulated, significantly shorter TSOLs were obtained when feedback was provided. An implication from this finding is that it is important to emphasize immediate responding when investigating pre-motor variables in a speech production task. These results provided support for the presence of a post-selection inhibition mechanism, but not an editing mechanism, during pre-motor encoding.

Another theoretical perspective that proposes a role for phoneme similarity effects is offered by Roelofs (1999). Within the WEAVER model of phonological encoding, Roelofs posits that featural similarity effects result because features are a part of the phonetic syllabary. He reasons that incorrect phoneme segments may be chosen more often when phoneme segments and syllable program nodes point to the same features. Thus, regardless of theoretical perspective and despite the lack of a commonly used operational definition for the concept of similarity, it is generally accepted that similarity effects may induce speech errors.

2.2.3 Segment to Frame Association and Serial Order

While phonologic encoding typically is conceived of as involving the two previously described levels of representation, frame structure and content, the activated content information also must become associated with the frame structure. According to Levelt and Wheeldon (1994), the way in which segments become associated with the word's frame is the second stage of phonological encoding. Shattuck-Hufnagel (1979) proposed the previously discussed scan-copier mechanism (see section on Models) to explain processing at this stage. Dell (1986) maintained the general ideal of the slots-and-fillers model, however, explained processing via the mechanism of spreading activation. As previously described, higher level processes spread activation to lower level processes and once items are activated, those with the highest levels of activation are selected to fill spots in the word's frame. Variations of this connectionist model for segment association are most typically used to describe the manner in which phonemes are selected and assigned to the frame. A primary issue related to the association of segments to the word frame is how serial order is accomplished. In the Shattuck-Hufnagel (1979) model serial order is accomplished by the spell-out of the words segments. Serial order errors occur when the scan-copier mechanism fails. Levelt (1989; 1992) addressed the necessity of a serial ordering mechanism for assigning segments to their slots when order is specified in the lexicon. He posited that the need is based on the demands of connected speech (see below). Serial order in Dell's model (1986) is accomplished through categorized segments and slots and through the spreading of activation. In this model, activation of segments occurs in parallel. Segments and frames are identified for their appropriate category (e.g., onset, nucleus or coda) and items are assigned accordingly. Thus, the segments with the highest level of activation are assigned to their specified positions in the frame. Dell (1988) revised this aspect of his model and included serial encoding of segments that are controlled by a word-shape device. An investigation by Meyer (1991) posed a challenge to the idea of parallel activation in the Dell (1986) model, as results from this study suggested that phonological encoding of segments within a syllable proceeded in a serial fashion.

In a series of experiments, Meyer (1991) examined phonological encoding within a syllable using the previously described form-preparation or implicit priming technique. Participants were presented with several mono- and di-syllabic words in which the phonemic similarity of the initial phoneme or of the rhyme component of the words in a set was manipulated. The results revealed faster reaction times for the condition in which word form onsets were homogenous, as opposed to heterogeneous for both mono- and di-syllabic conditions. The same facilitory effect was not found for phonemic rhyme similarity in either mono- or di-syllabic stimulus conditions. Additionally, priming effects for word onset and word-internal syllable onsets were about equal. Meyer interpreted these findings to suggest that the prime manipulation affected phonological encoding and not the motor aspects of production, as the facilitory effects of syllable internal onsets could not be due to presetting the articulatory apparatus. This conclusion appears to be supported by a previously discussed Roelofs and Meyer (1998) study that examined the role of shared phoneme content and shared aspects of metrical structure. Results from that study provided evidence of a facilitation or preparation effect, only in contexts in which initial phoneme segments and aspects of metrical structure were shared. Results from Meyer (1991) were further interpreted as evidence that there is sequential ordering of phonemes within syllables during phonological encoding and supported the Shattuck-Hufnagel (1979) model of phonological encoding.

Though operating from a different theoretical perspective, Kohn and Smith (1995) also examined serial ordering during phonological encoding, but in PWA. Based on Underspecification Theory, Kohn and Smith conceptualize that the lexicon is composed of underspecified representations and that it is organized according to the featural distribution of those stored representations. Within this perspective, the syllable is considered to be the unit of processing and as such a guide for further linear processing. These investigators describe phonological encoding as consisting of two stages; one stage involves the activation of the underspecified representations and the other involves completing the specification of the underspecified representations. For individuals with impaired lexical-phonological activation (impairment at the first stage), only partial information about segments may be available. This partial word information may result in the production of non-words or production of the target's phonological neighbor. Contrastively, according to Kohn and Smith, disturbed phonological planning (impairment at the second stage) presumes intact lexical-phonological level processing, but incomplete application of phonologic redundancy rules that are supposed to complete the initially underspecified representation. Kohn and Smith hypothesized that in phonemic planning deficits, activation of the representation may decay before phonemic planning is completed and that this is realized through frequent, incomplete, target-related productions. They further hypothesize that individuals with impaired lexical-phonological activation are more likely to produce non-words and words that are less similar (i.e., contained extra syllables) to the target than individuals with phonemic planning deficits. These hypotheses were examined in a study designed to determine whether phonemic planning proceeds in a serial, left to right direction or in parallel.

The participants in this study included 6 PWA, 3 with phonemic planning deficits and 3 with impaired lexical-phonological activation, as determined by specified criteria. The participants were only described as presenting with "fluent aphasia with phonologically impaired speech" (Kohn & Smith, 1995, p. 212) with no classical aphasic type specified and no evaluation of their sub-phonemic (motor) apparatus. Measures used to determine the participants' phonological deficit included picture naming, repetition and oral reading tasks, and a repetition and oral reading task of pseudowords. Participant group differentiation was based on the proportion of errors that were related fragments, verbal paraphasias, involved extra random syllables, and the production of noun and pseudoword production. A phonemic planning deficit was indicated if a participant produced many target related fragments, demonstrated a similar ability to produce real words and pseudowords and did not produce large numbers of non-word errors that contained unrelated extra syllables or verbal paraphasias. The authors stated that minimally, the production had to share something with the target (i.e., onset, consonant cluster, etc.) to be considered related. Relative to criteria for group assignment, individuals with impaired lexical-phonological representation produced targets with extra, unrelated syllables and their productions did not necessarily preserve the structure of the target.

The participants participated in several tasks, however only the data from picture naming and repetition tasks were reported in this study. Data were obtained from one of several assessments that occurred within 6 months post onset of a cerebrovascular accident. The data were collapsed across participants within a group because analyses revealed similar performance among them on several measures. Dependent measures were the proportion of target-related fragments that were word initial, the location of consonant errors by syllable, and the locus of consonant errors by onset/coda by syllable. There were no significant differences between groups on the proportion of target-related fragments that were word initial. However, no power, pre-selected alpha levels or effect size information were provided. The authors consider the argument from normal speech production that word onsets have a special status in word production as an explanation for these negative results. The location of consonant errors by syllable was reported to be statistically significant for the group with impaired phonemic planning; but not for the impaired lexical-phonological access group. Additionally, the impaired phonemic planning group produced significantly more errors in codas than in onsets, while this did not occur for the impaired lexical-phonological access group. Kohn and Smith also found that individuals with deficits in phonemic planning produced more errors with increasing syllable length. The authors suggested that their findings did not provide conclusive evidence about the direction of phonemic planning, but in general, interpreted their results as support for left to right phonemic planning. These findings should be interpreted cautiously, however, due to the many limitations of the study. No information was provided on data collection (i.e., same examiners, instructions) and there were a small number of participants in each group. Obtained null findings might be attributable to a lack of power. Limited information is provided on the stimuli and any stimulus or condition controls that might have affected individual performance (e.g., similar CV construction, phoneme frequency, etc.). Despite these limitations and the different theoretical motivation of this study, these results may be viewed as supportive of the serial nature of phonemic planning during spoken word production.

2.2.4 The mental syllabary

The third stage of phonological encoding according to Levelt and Wheeldon (1994) is accessing the mental syllabary. As stated previously, the mental syllabary is defined as "a repository of articulatory-phonetic syllable programs" (p. 239). It consists of pairs of phonological syllable specifications and syllabic gestural scores. The mental syllabary is posited "as a mechanism for translating an abstract phonological representation of an utterance into a context-dependent phonetic representation" (p. 24). In other words, the abstract phonological representation cannot be articulated, but the computed or accessed gestural score provides the translation necessary for the motor system to accomplish the production goal. Slots in syllable frames are conceived of as timing slots and phonetic material fills these slots. As previously discussed (see introduction), the abstract phonological representation is conceived of as being represented by tiers of information. Featural, metrical and intonational information is included in these tiers. The mental syllabary is necessary to allow for the syllabification processes that must occur with connected speech, as the goal of connected speech is to produce pronounceable and well-articulated strings of sounds. According to Levelt (1989) and Levelt and Wheeldon (1994), the gestural scores or stored syllable programs of the mental syllabary are not completely fixed, but have free parameters. These free parameters include loudness, duration, pitch, rate, and pause information. A mechanism called the Prosody Generator provides each syllable frame with information about those free parameters. The metrical information produced within the Prosody Generator is not stored, but is contextually determined and contributes to the phonetic spellout of stored phonetic syllable plans.

While Levelt characterizes processing within the mental syllabary as the final stage of phonologic encoding, the description of the processing that occurs at this level addresses the transformation of the phonological code into a code that can be used by post phonologic encoding processes. At this point the phonologic code is transformed into the phonetic plan and the role of timing and syllabification processes become more obvious. This transformation includes accessing gestural scores and incorporating the contributions of metrical and prosodic information. Van der Merwe (1997) similarly describes these processes as contributing to motor planning (See below). As the speech production process does not consist of only phonological encoding, other processes that are involved in the production of motor speech are described. The ensuing discussion will focus on those processes involved in movement for speech.

3.0 MOTOR PLANNING

In this section, the framework of Van der Merwe (1997) will be briefly expanded upon, as well as other conceptualizations of spatial and temporal organization for speech movements. Further elaboration of the concepts introduced in this section will be presented and integrated into the sections on disordered speech production as appropriate.

As indicated in the introduction, Van der Merwe (1997) proposed that in the motor planning phase of production, the symbolic units from the linguistic-symbolic planning stage must be transformed into a code that the motor system is able to use. She describes motor planning as the level at which a plan of action for turning phonemes into something able to be articulated, is developed through the specification of motor goals. The input to the motor system begins as “a sequence of invariant phonological units” (p. 11). These invariant representations determine the spatial and temporal specifications for each sound and form core motor plans, which are stored in sensorimotor memory. Based on the idea that the motor plan contains spatial and temporal specifications for movement, and that the assumed goal of the motor plan is to produce a phoneme that is described relative to place and manner of articulation, the motor plan is conceived of as articulator specific. According to Van der Merwe, both the context (e.g., sound environment) within which a motor plan is operating and the core motor plan for a phoneme may be adapted. Contextual adaptations may result in different speech behaviors (e.g., shortening a word, slowing rate). These adaptations might occur for a variety of reasons (e.g., pronunciation of a new or phonologically difficult word, attempts to overcome time constraints or environmental factors such as noise). Adaptation of the core motor plan of a phoneme occurs relative to "the context of the planned unit" (p. 12). For example, the spatial and temporal parameters adapt to meet the demands of variables such as speaking rate or coarticulation. This level of processing appears equivalent to the level of transformation that occurs between the formulator and articulator processes in Levelt's (1989) model.

Though Van der Merwe (1997) does not integrate her conceptualization of motor planning processes with any other production model, this will be attempted here, relative to the Levelt (1989) model. Similar to the Levelt model, Van der Merwe views the input to the motor system as the products of phonological encoding. The invariant phonemes, discussed in the Van der Merwe model, might reasonably be compared to the fixed parameters contained in the phonological tier system and stored in the mental syllabary, previously described by Levelt. It seems reasonable to hypothesize that the spatial and temporal goals specified in Van der Merwe's model, use the information provided in the organized tiers of phonetic content postulated in Levelt's model. Van der Merwe's core motor plans are derived from the phonemes made available to the motor plan and may be conceptually similar to the articulatory gestures described in Levelt. The "invariance" in Van der Merwe's model is determined by the sequence of phones in a syllable that are the inputs to the motor plan. Van der Merwe suggests that during speech production, the core motor plans are recalled from sensorimotor memory. Similarly, Levelt, argues for an inventory of frequently used, stored syllable plans. It seems reasonable to conclude that the sensorimotor memory posited by Van der Merwe and the mental syllabary proposed by Levelt, are similar, if not equivalent.

One issue that might arise in a comparison of these models is whether processes are assigned to the same level. Van der Merwe (1997) places core motor plans within the motor planning level. While there are not always directly equivalent processing levels between Van der Merwe and Levelt (1989), within the Levelt model it might be reasonable to posit that the core motor plans described by Van der Merwe, are equivalent to the stored gestural scores that compose one part of the information stored in the mental syllabary. If accurate, this perspective appears to reveal dissimilarity between the two models on level assignment for the gestural score/core motor plan representation. It is unclear whether the components of the mental syllabary are best conceived of as being within the level of phonological encoding, however, one might hypothesize that the gestural score information would otherwise be conceived of as a separate motor memory store that is a part of the phonetic plan. It is acknowledged that this raises other issues for interpretation of the model and is only offered as another possible way in which to conceive of processing at this level. For example, if the gestural score information was conceived as being retrieved from a separate motor memory store, issues of interest might include considering the necessity of a separate phonological memory store as well as issues regarding the organization and time-course of retrieval of information from the motor memory store. None-the-less, within this conceptualization, the phonetic plan is initiated as activated representations make contact with their relevant articulatory gestures or gestural scores. According to Van der Merwe the influence of context is evident at this level. She states that if the context in which the motor plan must operate is too complex (e.g., coarticulatory or speaking rate demands), the plan might have to be adapted. The parallel idea within the Levelt model would be incorporated in the concept of the Prosody Generator and the free parameters. Syllabification processes and the integration of melodic and prosodic information contribute to shaping motor goals. The free parameters allow for segments and phrasal boundaries to be changed based on the conditions necessary to produce well-articulated connected speech, and allow for changes to speaking rate. Thus, both models seem compatible with intrinsic timing models at this level of processing, particularly models of gestural patterning. The concepts of adjusted context and free parameters are consistent with the concepts of coarticulation and interaction and adaptation among interacting units of the post-phonological, pre-movement motor systems as defined by Van der Merwe. One apparent discrepancy between Van der Merwe's conception of representation at the level of motor planning and that of a gestural phonology model (i.e., Browman & Goldstein, 1992) is that Van der Merwe describes processing at the motor planning level as articulator specific. Gestural patterning models, however, do not focus on individual segments or individual articulators, but focus on how spatial-temporal movement goals are organized and realized, relevant to several articulators (Browman & Goldstein, 1992). The Levelt model does not specify that gestural scores are articulator specific as he incorporates the theoretical perspective of Browman and Goldstein into his model. In general, the Van der Merwe and Levelt models propose similar processing between the phonological encoding and motor planning levels. Van der Merwe's model, however, attempts to provide a clear delineation between processing that occurs as a part of linguistic-symbolic processing and that which is part of sensorimotor processing. Additionally, with particular relevance for differential diagnosis of motor speech disorders, she attempts to define and provide specific delineation of those processes that occur during the different stages of motor planning, programming and execution. Though acknowledged that it is not the goal of this model, one shortcoming of the Van der Merwe model is that it does not explicitly account for serial ordering processes at the level of phonologic encoding.

4.0 MOTOR PROGRAMMING

A number of motor control models have been proposed to describe how speech movements are organized and function. These models include dynamic systems (Kelso, Saltzman, & Tuller, 1986), gestural patterning (Browman & Goldstein, 1992) and motor programming models (Sternberg, Knoll, Monsell, & Wright, 1978). These models differ on a number of parameters including the role of feedback, how contextual influences are explained and how the degrees of freedom within the motor system are controlled (Kent, Adams, & Turner, 1996). Included in Van der Merwe's (1997) theoretical framework for speech production is a motor programming component. This model uniquely separates motor planning and motor programming processes and has an anatomical and neurophysiologic basis for doing so. The model also has direct implications for differentiating certain neurogenic communication disorders. The motor programming stage of the model describes how motor control is organized after the spatial and temporal goals of speech movements have been determined, but before movement actually begins. Unlike processing at the motor planning level, which Van der Merwe describes as articulator-specific, motor programming processes are described as muscle specific. Van der Merwe's review of the motor programming literature reveals that the focus on muscle commands is a part of the motor program concept. The muscle-specific focus of the motor program does not mean that the program focuses on only one muscle, but that the focus of motor programming occurs at the level of the muscle. Though it has been acknowledged that alternative accounts of speech motor control have been offered (Gracco & Abbs, 1988; Guenther, Hampson, & Johnson, 1998; Saltzman & Munhall, 1989), the advantages and disadvantages of these alternative views will receive no further discussion, as those issues are beyond the scope and specific interest of this study.

Van der Merwe (1997), acknowledges that there are many perspectives on the details of how motor programming processes should be conceptualized, but in her framework, motor programming "entails the selection and sequencing of motor programs of the muscles of the articulators . . . and specification of the muscle-specific programs in terms of spatiotemporal and force dimensions such as muscle tone, rate, direction, and range of movements" (p. 16). Her conceptualization includes a role for both sensory and internal feedback, with the purpose of updating and controlling programming, respectively. Van der Merwe views motor programming as the level at which specific movement parameters are computed for a movement as it is realized over time. Thus, based on her conceptualization of motor programming, motor programs can be affected relative to disturbances in both the selection and/or sequencing of motor programs, and/or in computing the parameters for the aforementioned variables of tone, rate, direction and range of movements. The division of motor processes into separate levels in which specific processing events occur, allowed for hypotheses about levels of processing affected in neurologically disordered individuals. For example, defects in rate and distortion errors may implicate a deficit at the motor planning level of production that result from trouble adapting the core motor plan while difficulty with movement initiation might result from a motor programming deficit. According to Van der Merwe, the rationale for this perspective is based on neuroanatomical and neurophysiological data, which suggest that motor association areas are implicated during motor planning, but that the nucleus accumbens and supplementary motor area

(SMA) are important in establishing the link between the intent to move and movement initiation, structures that are proposed to be important for motor programming. It is, however, important to acknowledge that the SMA also is proposed to be active during motor planning, thus limiting a clear assignment of movement initiation deficits to the level of motor programming. While acknowledged by Van der Merwe, deficits at more than one level are possible, this framework provides a theoretical basis for distinguishing among some, though not all neurogenic speech production disorders. This framework is used to further contextualize the production process, as the Levelt model (1989) does not address the motor planning and motor programming levels of production in detail. As these levels of production may be disrupted in several neurologically based speech disorders, it is appropriate to have at least a general understanding of the processing at these levels in order to select appropriate criteria for participant selection, for the study of level-specific disorders such as those in the present investigation.

5.0 PRODUCTION ERRORS IN NORMAL ADULT SPEAKERS

5.1 ELICITATION TECHNIQUES

Investigations that have examined the frequency of production errors in everyday speech in normal adults have reported the occurrence to be about one error per 1000 words (Dell, et al., 1997). Meyer (1992) questioned the usefulness of speech error data in providing evidence about phonological encoding. She argued that speech error analyses have yielded little specific information about speech planning processes or the time course of phonological encoding. From her perspective, error analyses have not made substantial contributions to understanding issues such as the structure or content of representations in speech production nor clarified the role of features in the production process. Meyer identified methodological issues such as listener bias by judges and experimental elicitation techniques as limitations of speech error analyses. She acknowledged that her criticism of perceptual judgments was easily corrected with audio-recording of produced utterances. Her criticism of listener bias by judges might also be addressed through additional or more specific analyses (i.e., narrow phonetic transcription, acoustic, and kinematic analyses). She argued that experimental error induction techniques might change the normal speech production planning process, but acknowledges the advantage of the ability to control the stimulus environment. This criticism, while valid, is not specific to the study of speech production errors, but is relevant to most researched speech and language issues. Other limitations of speech error analyses identified by Meyer that are less easily overcome are the inherent ambiguity of some errors (e.g., word onset or syllable onset error) and probabilities of error occurrence. However, Vousden, et al. (2000) provided an example of a study which has attempted to resolve one such error ambiguity with the finding of a significant syllable onset effect separate from the word onset effect. Additionally, a few studies have proposed methods to address the issues of probability of error occurrence and chance estimates (Dell & Reich, 1981; Gagnon, et al., 1997; Vousden et al.). Meyer proposed that a better strategy for understanding phonological encoding was to develop a working model of correct phonological encoding, as opposed to a model based on conclusions drawn from speech error data, to develop hypotheses about correct speech production and then to develop methods to test those hypotheses. This perspective represents an alternative strategy for understanding phonological encoding but it is an empirical question as to whether or not it is a better strategy. Keeping in mind what is understood about phonological encoding based on acquired evidence from speech error analyses, one might argue that both approaches have value and make relevant but different contributions to our understanding of the phonologic encoding process.

Though much of the speech error literature is based on speech errors obtained in spontaneous conversation, other methods have been used to elicit speech production errors. Baars, et al. (1975) developed a task in which young, non-brain damaged participants were visually exposed to several interference word pairs and then a target word pair. Interference word pairs were stimuli that were not produced by the participants and in which the initial consonants of each word in the pair were in the reverse order of the to-be-produced target word pair. This manipulation creates an exchange error bias in the individual producing the stimulus. In this study only 42 of 360 potential utterances (or 12%) resulted in errors. This technique was also used by Dell (1986) to elicit production errors in a group of young non-brain damaged participants with a reported error rate of 10.2%.

Wilshire (1999) used a "tongue-twister" task to elicit speech production errors in middle-aged adult speakers with error rates that range from approximately 4% – 13% depending on the experimental condition. Tongue-twisters are typically thought of as phonologically manipulated (structure and or content) sentences, however, the task used by Wilshire (1998, 1999) involved phonologically manipulated strings of single words. In the 1999 study, Wilshire varied phoneme similarity and repetition pattern. The participants were required to provide four repetitions of a visually presented string of word, at a slow pace (1.67 syllables per second) in time with a metronome, and without pausing. The slow pace was used to decrease the chance that errors were created by an inability to program or execute accurate speech movements. Data were transcribed using broad phonetic transcription. The error rate ranged from 1.5% - 12.5% with an average of 4.5% overall. Participants were middle aged adults between the ages of 40 and 69 years. The results of interest for this study revealed a significant difference for phoneme similarity, but not for repeated phonemes. There were no significant findings related to the pattern of phoneme presentation. Significant findings were obtained relative to the condition in which the same sequence was repeated multiple times compared to the control condition (i.e., production of single words with no repetition). That is, items classified as "alliterating/similar" elicited significantly more errors than items classified as "alliterating/dissimilar" (p. 65). Descriptively, most obtained errors were reported to be single-segment consonant errors of a contextual nature. A high number of anticipation errors (about 78%), but few perseveration errors (about 22%) were produced. While errors in a different position from their source did occur, significantly more errors maintained the same position as their error source. Because many of the results parallel those found from other elicitation methods, the authors interpret their results as indicative of the validity of using the tongue twister paradigm for investigations of phonologic encoding.

Use of the tongue twister paradigm has also been used to investigate the role of phonology in reading tasks (McCutchen, Bell, France, & Perfetti, 1991; McCutchen & Perfetti, 1982). To examine the role of phonology in reading, McCutchen, et al. (1991) manipulated the similarity of initial consonants of words in a sentence, among other variables, to create a tongue twister effect in a silent reading task. In one condition participants were given tongue twisters that repeated phonemes and control sentences in which phonologic content was not manipulated. Participants also performed a digit recall task in which they were presented five, one or two digit numbers that began with the same phonemes that were manipulated for the tongue twister sentences. Participants were first presented with the digits, then asked to read one of the sentences and judge it for semantic acceptability and finally, asked to recall the digits. A button response indicated whether or not a sentence was semantically acceptable and participants typed the digits that they remembered. The investigators determined that semantic acceptability judgments were significantly slower in tongue twister sentences than in control sentences and that there was an interaction between semantic acceptability and the tongue twister/control sentence variable. Response times for tongue twister sentences that were judged acceptable were significantly longer than those sentences that were judged unacceptable. When the sentence judgment task was paired with a digit memory task in which the initial consonants of the to-be-remembered digits were either similar or dissimilar to the sentence judgment stimulus item, results revealed that participants recalled significantly more digits with sentences judged as acceptable, but more importantly, remembered significantly more digits with control sentences than with tongue twister sentences. Additionally, there was a significant interaction between digit type and sentence type. Participants recalled significantly more digits when remembering digits with initial fricatives, than with initial stops. McCutchen, et al. (1991) interpreted these results to support the phonological basis of the tongue-twister effect. Similarly, McCutchen and Perfetti (1982) reported significantly longer reading times when tongue-twister stimuli were used and attributed their finding to phonetic similarity effects. Though studies that manipulate phonologic variables to induce speech errors may be criticized because the planning processes of the contrived experimental condition may be different from spontaneous speech, these studies suggest that tongue twister tasks are effective for inducing speech production errors. Further, the form of the errors tends to parallel those observed in spontaneous speech, adding to their validity.

5.2 ERROR TYPES AND FREQUENCY

Many studies have investigated the speech production errors of non-brain damaged participants (Garnham, et al., 1981; Shattuck-Hufnagel & Klatt, 1979). Studies examining serial-order, phoneme segment or phonological errors typically categorize the errors as anticipation, perseveration, or exchange/transposition errors. Anticipation errors are generally defined as errors in which a segment is produced earlier than it should, with its assumed error source in an upcoming part of the utterance (Dell, 1986). Dell, et al.(1997) defined an anticipation error as occurring when "all intended occurrences of the intruding constituent are after the target location" (Dell, et al., 1997, p. 145) (e.g., "*r*ed *b*ag" becomes "*b*ed *b*ag"). Perseveration errors are defined by the erroneous repetition of an already produced segment or as defined by Dell, et al. (1997) when “all intended occurrences are before the target location” (p. 145) (e.g., “*r*ed *b*ag” becomes “*r*ed *r*ag”). Exchange/transposition errors are defined by two phonemes replacing each other in their target locations (e.g.,. “*r*ed *b*ag” becomes “*b*ed *r*ag”). It has been reported that these contextual errors occur with high frequency in the speech production of non-brain damaged individuals (Schwartz, et al., 1994). Analyses of the spontaneous productions of normal participants (Cohen, 1966/1973) have typically revealed that phonological errors are characterized most frequently by anticipation errors (van den Broecke & Goldstein, 1980), followed in frequency by perseveration and transposition errors (Vousden et al., 2000). For example, in a corpus of naturally occurring speech errors, Vousden et al. reported an error type frequency occurrence of 35%, 27%, and 10% for anticipation, perseveration and exchange errors, respectively. Non-contextual errors or errors in which a recognizable source is not present in the target utterance do occur in the speech of NBD persons, however, reported data are ambiguous because other error types (i.e., anticipations, perseverations, exchanges) are sometimes not distinguished from the non-serial order errors (e.g., Shattuck-Hufnagel & Klatt, 1979).

Distortion errors are not typically identified in the speech production errors of NBD participants. Odell, McNeil, Rosenbek, and Hunter (1990) characterized a distortion as “an attempt at the target that did not cross the phoneme boundary but that was produced with perceptible place, timing, manner, or voice deviation(s) from the correct production” (p. 347). Based on the speech production model of Van der Merwe (1997) and its assertions regarding contextual and core motor plan changes, there is no reason to conclude that NBD persons do not produce distortion errors. Furthermore, McNeil, et al. (1997) argued for the use of narrow phonetic transcription for speech production errors when perceptual analysis is used so that all characteristics of the speech error might be captured. Without this level of analysis it is not possible to determine if the errors categorized in the various studies of NBD speakers are errors that can solely be attributed to the level of phonological encoding (McNeil, et al.; Shuster & Wambaugh, 2000).

Dell (1986) has developed a model of normal speech production that provides a theoretically based explanation for how whole segment serial-order speech production errors occur. The models of Dell (1986) and colleagues (Dell, et al., 1997) make predictions regarding the relative frequency and proportions of serial order errors in neurologically normal individuals. In the Dell model (1986), errors in serial order may result as a consequence of spreading activation. Speaking rate is identified as a variable that affects the frequency of occurrence of specified serial order errors. Dell's model proposes that the interaction of speaking rate and spreading activation can affect phonological encoding such that predicted ratio patterns of phonological serial order errors (i.e., anticipations, exchanges, perseverations) may occur. A strength of this model is its ability to make predictions about the interaction of speaking rate, especially serial order errors, with phonological encoding processes in order to explicate the mechanisms of serial order error generation. The model of Dell (1986) and colleagues (Dell, et al., 1997) will be elaborated upon in the next section relative to the mechanisms of serial order error generation.

6.0 APHASIA

The literature is replete with descriptions of production errors in the speech and language of PWA (Blumstein, 1973; Joanette, Keller, & Lecours, 1980; Kohn & Smith, 1995; Schwartz, et al., 1994). The speech production errors of PWA are typically viewed as reflecting disrupted linguistic-symbolic processing. McNeil and Kent (1990) point out, however, that while this specified level of disruption appears distinct, traditional classification within the disorder of aphasia is based on both language and speech production behaviors and that many of the speech production behaviors are as likely, or even more then likely, to be attributable to the motor system as to the linguistic system. According to Van der Merwe (1997), speech production errors that result from disruption to the linguistic-symbolic level of production should result in errors that affect the selection and sequencing of phonemes, as well as lexical, semantic, and syntactic processing. Phonological-level errors should include phoneme substitutions and serial order errors without distortions (McNeil, et al., 1997; Van der Merwe, 1997). Speech production errors that result from disruption to motor planning and motor programming processes should result in temporally or spatially disrupted speech with speech production errors that are perceived as distortions and sound-level substitutions (McNeil, et al., 1997). McNeil, et al. proposed that distorted sound substitutions are not characteristic of individuals who present with only disturbed linguistic-phonologic level processing. A distorted phonological paraphasia is a phoneme error that is characterized by temporal, spatial or prosodic differences (Odell, et al., 1990) as described above, but one that maintains the essential acoustic characteristics of the intended phoneme. The resulting sound is not a completely accurate acoustic representation of the phoneme. Van der Merwe's proposed theoretical framework has a neurophysiologic basis and within this framework she acknowledges that some neural structures are involved at multiple levels of functioning, and that "cooccurring dysfunction in more than one phase of processing" (p. 17) is possible. As an example, aphasia and AOS frequently co-occur (McNeil & Kent, 1990). But even though there is the possibility of both linguistic-symbolic and motor level processes being disturbed in individuals with aphasia, and despite the use of speech characteristics to describe individuals within the traditional aphasia classification of Broca's aphasia, according to McNeil, et al. some speech production errors (i.e., undistorted sequencing errors) can be attributed to a particular production level.

Within the "Boston" classification system of aphasia, six types of aphasia are typically identified. Of those six, four types, Wernicke's, Conduction, Anomic, and Transcortical Sensory aphasia have been characterized by intact-to-relatively-intact overt production of speech sounds (Goodglass, 1993). Of these types, CA is the only one typically characterized by the frequent occurrence of phonemic paraphasias (Goodglass, 1993). Goodglass describes the speech production characteristics of CA to include: impaired repetition, fluency characterized by short bursts of speech, difficulty in sequencing phonemes, good articulation, normal rate of speech, intact intonation, and difficulty producing polysyllabic words. He states that phonemic paraphasias, anomia and multiple attempts at self-correction frequently occur. Individuals with CA are generally characterized as having relatively preserved auditory comprehension (Goodglass, 1993). Based on this widely accepted characterization of CA, the speech errors of these individuals are assumed to have a cognitive-linguistic basis and to be the result of disruption at the phonologic rather than motor level of encoding (Buckingham, 1992). Individuals with CA typically produce phonemic paraphasias that are characterized by substitution, addition, omission, and transposition errors (Blumstein, 1973; Buckingham, 1992; Joanette, Keller, & Lecours, 1980). Buckingham (1986) assigns these disruptions in phonological planning processes to the Positional level of the Garrett (1984) model. Blumstein (1973) conducted a study that revealed that the phonological errors that are associated with aphasia include serial order errors as well as sound substitutions. Serial order errors include transposition (exchange), anticipation and perseveration errors (Schwartz, et al., 1994). According to Buckingham (1992) and Schwartz, et al. the speech sound production error patterns of individuals with aphasia are similar to those of normal slips of the tongue. Odell, et al. (1991) conducted a perceptual analysis of vowel and prosody production in a single-word imitation task in individuals with CA, AOS and ataxic dysarthria. Narrow phonetic transcription was used to capture production errors and the results revealed that CA participants produced more substitution than distortion errors and few stress errors. These results are in accordance with the assertions of Buckingham (1992) and can be interpreted as further support for a segmental level deficit in CA as few sub-segmental level errors were evidenced.

Schwartz, et al. (1994) used an interactive spreading activation model of lexical retrieval to examine production errors in NBD participants and in a single individual with jargon aphasia. Investigations of speech production errors typically focus on the type and frequency of produced errors. These authors developed their own theoretically based error categorization and after identifying production errors, compared those with a previously collected normal sample obtained by Garnham, et al. (1981). The data from the PWA were obtained from an unpublished

1996 study by Bloch (as cited in Schwartz, et al. 1994). The results revealed a significantly higher proportion of sound-level errors in the jargon aphasic as compared with the normal speakers' samples. Additionally, there was a significant difference in the proportion of errors that were "simple" or "complex" between the aphasic and normal samples. "Simple" errors were single segment errors, whereas "complex" errors involved more than one phoneme unit. The PWA produced significantly more complex than simple errors. Of further relevance from this study is the comparison of the frequency of anticipations and perseverations in the person with jargon aphasia as compared with the normal speakers. The results revealed significantly more perseveration errors in the individual with aphasia as compared with the normal speakers. The authors report that this finding was in agreement with a previous analysis of this individual's speech. Interpreted relative to the Dell (1986) spreading activation model, Schwartz et al. proposed that the error proportion results were consistent with decreased connection strength in the model. This was demonstrated in the simulations reported by Dell, and further supported by experimental methods that required young normal speakers to increase their speaking rate. While interesting, the results of this study must be interpreted cautiously as the results and interpretation of behavior are based on only one individual, whose functional lesion and deficit were substantively underspecified.

Wilshire and McCarthy (1996) examined the phonological encoding impairment of an individual diagnosed with mild CA. The phonologically impaired participant used in this study was not tested for speech or motor level impairment and no audiologic or visual acuity information is provided. The individual was described as demonstrating normal or near normal skills on comprehension or receptive language tests and normal to below-normal performance on some expressive language and writing tests. An auditory-verbal short-term memory deficit was reported. It was suggested that the first four of the several experimental conditions helped to establish the presence of a phonological impairment. Results from the first experimental condition, a picture-naming task manipulating word length as measured by number of syllables, revealed predominately single segment substitution errors, and frequent successful repeated attempts at the target, with significantly ($p<.001$) more errors on longer syllables. Though not specifically stated, based on examples, it appears that single segment errors refer to phoneme errors and not feature errors. It should be noted that these results do not provide strong evidence for a phonological level impairment only. McNeil, et al. (1997), argued that none of the reported characteristics of the participant reported by Wilshire and McCarthy can uniquely be attributed to the phonological level. That is, these same speech errors can as easily be attributed to a motor-level impairment and also occur in AOS. This means that within this framework, the results of the first experimental condition may not be confidently attributed to a deficit in phonological encoding.

The goal of this study was to examine different aspects of the error productions of a phonologically impaired individual and to compare it with that of normal speakers. The authors made a distinction between a phonological retrieval deficit and a deficit in "post-retrieval phonologic encoding processes" (Wilshire & McCarthy, 1996, p. 1066). Acknowledging that phonological performance may be influenced by a number of phonological variables, the authors exposed this one participant to several speech production manipulations. Wilshire and McCarthy state that the proportions of error types produced by phonologically impaired persons are different from that of normal speakers. Citing Garnham et al. (1981) and Nooteboom (1969), they erroneously report exchange errors to be most common in the speech production errors of normal speakers. (Garnham et al. reported 22 anticipation segment errors compared with one exchange segment error). This reported frequency of exchange errors in normal speech production, relative to anticipation and perseveration errors is in direct contrast to other reported frequency data (Cohen, 1973). They accurately state that exchange errors are relatively rare in the productions of individuals with aphasia (Schwartz et al., 1994). Similar to Schwartz et al., these researchers state that perseveration errors have been noted to occur more frequently than anticipation errors in the speech of PWA. They suggested that network models might provide a way to account for the error patterns produced in phonologically impaired speakers (i.e., frequency of word onset errors, contextual or non-contextual in nature). Wilshire and McCarthy proposed that examining the error patterns present in individuals with impaired phonologic encoding might also help inform connectionist models of normal phonological encoding.

In a further evaluation of this participant's phonological encoding ability, performance on multi-syllabic, picturable nouns across naming, oral reading and repetition tasks and the effects of lexicality (word vs. non-word) in reading and repetition tasks was assessed. Overall results revealed significantly fewer errors on repetition tasks and significantly more errors on non-word tasks. A significant syllable length effect was obtained on reading and repetition tasks and poorer performance was demonstrated on picture naming tasks than on word repetition tasks. The authors interpreted the poorer performance on picture naming than word repetition tasks as evidence that errors were not a direct result of a short-term memory deficit as the memory load for picture naming should be less than that required in word repetition tasks. Alternatively, this result might be explained by a deficit or inefficiency in phonological retrieval. Though transcription procedures, error coding, reliability data, and a definition of phonemic paraphasias were not provided, the participant's errors (with a few exceptions) were classified as single-segment "phonemic paraphasias" (Wilshire & McCarthy, 1996, p. 1068). Based on examples provided, it appears that the authors were referring to phonemes that were misordered, added or omitted. The authors claim that errors in phonological encoding were produced regardless of task requirements, further supporting their assertion that an individual with a phonological encoding impairment will produce errors whenever phonological processing is necessary.

Next, the effects of phonological similarity and speech rate were examined. Manipulation of both factors was motivated by the Dell (1986) model. It was hypothesized that the amount of available planning time would have an affect on phonological similarity. Two pre-determined speaking rates were used in this condition and rate was manipulated using a metronome. The authors claim that speaking rates were "kept well within the articulatory capabilities of the patient" (Wilshire & McCarthy, 1996, p. 1073) and that the fast rate was "still considerably slower than estimates for spontaneous speech" (p. 1074). Stimuli were written and present throughout the production task and consisted of two sets of 16 CVC word quadruples. One set contained consonant pairs that frequently interacted (similar) and the other set, consonant pairs that did not frequently interact (dissimilar), all based on the errors of normal speakers from the Shattuck-Hufnagel and Klatt (1979) corpus. Each quadruple of words was immediately repeated four times. From this condition, the number of incorrect words produced within each of the 16 similar and 16 dissimilar CVC word quadruples was derived. The results were collapsed across the four repetitions of each item and revealed no significant differences between phonological similarity conditions. Significantly more errors were produced on words in the fast rate condition than the slow, however, no data were provided as evidence that the productions at each speaking rate were significantly different from each other. Further analyses of these experimental data revealed more single phoneme errors and more final consonants errors than initial consonant errors within each rate. Wilshire and McCarthy report that none of the participant's errors were articulatory/phonetic in nature however, without knowledge of transcription procedures and coding reliability, this claim is unsupported. The authors attribute the participant's performance on this task to the high demands placed on phonologic encoding processes. Two more conditions were administered using a similar repetition task. In the first of these conditions, the effect of upcoming context on error production was assessed. Stimuli were presented either as the quadruple, such that all four syllables appeared at one time, or syllables from a quadruple unit appeared successively in a random order. There were no significant differences in the error rate between these tasks. Though confounded by multiple repetitions of the target (there were five immediate repetitions of each word quadruple when words were presented successively) the ratio of anticipation to perseveration errors was calculated. The results revealed that significantly more anticipation errors were produced in the quadruple unit repetition task (all four syllables presented at the same time) than in the other tasks. Data on the successive task were not provided due to ambiguity about error classification. In a final experimental condition, the performance of the phonologically impaired participant was compared to 6 normal participants on a number of variables including the effects of phonological similarity, the lexicality effect, the anticipation to perseveration ratio, and the frequency of occurrence of errors in different word positions. One speaking rate was assessed which was different for the phonologically impaired participant than for the normal group. The results from this condition revealed that unlike the normal group, the phonologically impaired individual did not demonstrate a phonological similarity effect. The normal participants produced significantly more errors on the phonologically similar, relative to the phonologically dissimilar stimuli. Results revealed a lexicality effect and a similar anticipation to perseveration ratio for both the phonologically impaired participant and the normal group. Additional findings revealed that while the phonologically impaired participant produced a similar number of initial consonant errors, he produced substantively more vowel, final consonant, multisegmental, whole word and unclassifiable errors than the normal group. The authors interpreted these results within the framework of the Dell model (1986, 1988) and concluded that in general this model was useful in explaining these behaviors for this individual with a phonological impairment deficit. According to the authors, the error performance of normal and phonologically impaired participants has been difficult to compare in previous studies because different tasks and methods have typically been used for each group. The results of this study should be viewed with caution for a number of reasons, not the least of which is that only one participant (especially considering the well-established variability of PWA) was studied. Additionally, these data do not provide convincing evidence that the participant presented solely with an impairment of phonologic encoding, as sub-phonemic level analyses were not provided.

Though it is widely accepted that the speech production errors of CA are generally attributed to a disruption of phonological encoding (Buckingham, 1986), this does not imply that individuals with CA cannot demonstrate concomitant motor level deficits (McNeil, Weismer, Adams, & Mulligan, 1990). Kent and McNeil (1987) examined the relative timing of sentence repetition in 3 NBD participants, 3 persons with AOS and for 2 persons with CA. The results of the segment and intersegment durations, voice onset time and formant trajectory data, were interpreted as preliminary evidence for a phonetic-motoric level deficit accompanying the phonologic deficit in the 2 individuals with CA. These results were obtained despite the fact that on clinical exam they had not demonstrated any signs consistent with motor level impairment. Similarly, Clark and Robin (1998) examined motor programming and temporal and amplitude parameterization in a non-speech task in individuals with AOS and CA. Though based on only 4 participants, these authors interpreted their results to suggest that while all CA participants did not perform normally on all motor control measures, the demonstrated differences did not appear to be characteristic of CA. Clark and Robin suggested that the demonstrated motor control deficits were concomitant with the linguistic disruption present in CA but were not characteristic of the disorder. In another non-speech task, McNeil, Weismer, et al. (1990) compared the isometric force and static position control of oral structures among normal, and ataxic dysarthric, AOS and CA participants. Individuals with CA performed significantly different from the normal group on a few contrasts, but also differed on many contrasts from the dysarthric and AOS groups. Though based on small sample sizes, the results of these studies suggest that there may be some motor control differences from NBD speakers in the motor systems of persons with CA however further evidence needs to be acquired.

Many investigators have theoretically (Blumstein, 1973; Dell, et al., 1997; Vousden, et al., 2000; Wheeler & Touretzky, 1997) or experimentally (Kohn & Smith, 1990; Schwartz et al., 1994; Wilshire & McCarthy, 1996) attempted to compare the speech production errors of NBD participants and PWA. Dell, et al. (1997) developed a model that "makes predictions about the relationship between speaking rate, practice, overall error rate and the extent to which errors are anticipatory or perseveratory" (p. 123). The authors extended the models' assumptions to hypothesize about and predict the behavior of these variables in PWA. Similarly, Wheeler and Touretzky and Vousden, et al. extended their models to account for the speech production errors in aphasia. Although these models did not make specific predictions regarding the effects of speaking rate on serial order errors. Vousden, et al. did discuss how a parameter of their model could be adjusted to obtain the predicted speaking-rate error proportions that were proposed by

Dell, et al.. However, no data were presented as the authors assert that this is an area that exceeds the current state of the model.

The Dell, et al. (1997) model makes assumptions about how serial order is maintained and about the relationship between specific variables identified as relevant for serial order behavior in speech production. Though not central for this discussion, the primary prediction of the model is that the frequency of specific phonologic error types can be predicted by overall error rate. This prediction, as well as others, is based on an interactive spreading activation model that incorporates a competitive queuing mechanism. According to the authors, the competitive-queuing mechanism is adopted because it is based on learning and serial-order principles. The authors propose that a theory of serial-order in speech production must be able to "activate the present, deactivate the past, and prepare to activate the future" (p. 123) and must contain a governing mechanism that is able to do this whether or not the sequence is novel. The occurrence of anticipation and perseveration errors is thought to reflect the time focus of the production system on the past or on the future, as "the tendency for a system to produce anticipations and perseverations should be related to the relative activation of the past, present and future" (p. 129). Thus, while the errors result from different disturbances in the production system, the disturbances are related by a time dependent mechanism (Martin & Dell, 2004). Dell, et al. examined the frequency of occurrence of these error types relative to age, stimulus familiarity, rate of speech, and the presence of aphasia. The latter two of these are of primary interest for this discussion. The ability of the model to deal with the past, present and future is conceptually controlled by "turn-off," "turn-on," and prime functions (p. 128). Conceptually, the self-inhibition that occurs after a unit is selected and its activation starts to decay allows for the "turn-off" function. The "turn-on" function is facilitated by the inhibition that occurs with the “turn-off” mechanism and is a function of which unit is most highly activated. Candidacy for the present also is facilitated by the prime function. In order to activate the future, this model incorporates a prime function that operates through activation of the plan representation. In general, development of this plan provides anticipatory activation for upcoming elements in the unit. That is, upcoming units receive at least partial activation. This model is composed of three levels of units and the competitive queuing mechanism is the mechanism that allows for serial order behavior. One level of units consists of the plan units. An example used by Dell, et al. is the word “cat.” The next level is composed of the response units or phonemes that are activated to produce that representation (i.e., /k/, /Q/, /t/). The third level is composed of the competitive filter. There are excitatory connections between the top two levels of units. For a target plan unit, the initial phoneme is most highly activated and activation progressively decreases from the beginning to end of the unit over time. The units are associated with a time-varying signal that is associated with the target from beginning to end. Activation levels of the response units are copied to the competitive filter or third layer of units. In the competitive filter, the units compete with each other and the most highly activated unit wins the competition and inhibits the selection of other units. After selection of the target phoneme, inhibition of the target occurs at the competitive filter level that facilitates the selection of the subsequent target phoneme. The authors state that serial order is maintained within the model because competition between the activation levels of the relevant planning and response units occurs in the competitive filter allowing activation at the level of the response unit (the middle layer) to be maintained. Because the competition and inhibition take place at a separate level, the model is able to maintain anticipatory activation for future units in the middle level of the model. Thus, this model accounts for the ability to prepare for the future through the excitatory connections from the plan to response unit levels, as well as activation of the present and deactivation of the past through the inhibition in the competitive filter. While the competitive-queuing mechanism allows for a sequence to be stored and reproduced, it does not explain how novel sequences are ordered during phonological encoding. For this, Dell, et al. incorporated the notion of rule-governed frames as part of the plan (Shattuck-Hufnagel, 1979; Dell, 1986). Categorically specified slots provided in the frame control the serial order of a novel sequence. Order is only stored in the structural nodes, is kept separate from content information, and is controlled through the mechanism of forward lateral inhibition.

Dell, et al. (1997) made several predictions from this model, including predictions about serial order error proportions. To reiterate, serial order principles are a part of the model, it is proposed that it is able to account for activation of the present and future and inhibition of the past. Based on the assumptions about initial activation levels and the behavior of spreading activation, it is asserted that the model is able to predict the probability of different error types. According to Dell, et al., the present and future are linked by the excitatory connections from the plan to response units. Anticipatory activation contributes to activation of the present and future and is able to occur because inhibition takes place at the level of the competitive filter. The authors developed an anticipatory proportion (AP) metric that is defined as "the proportion of anticipation and perseveration errors that are anticipations" (p. 125). Relative to the presence of aphasia, Dell, et al. proposed that PWA should produce a lower AP. They review findings in the literature, particularly those of Schwartz et al. (1994), which reveal perseverations errors as prominent in the speech production errors of PWA, relative to NBD participants. Dell, et al. calculated the AP proportion of the participant with aphasia presented in Schwartz, et al. and reported it to be substantively lower than that of the non-aphasic speakers from that sample. No other empirical data are provided. Dell, et al. proposed that the AP behavior of PWA might result from decreased activation caused by reduced connection weights within the lexical network. This perspective was previously suggested by Martin, et al. (1994) as a potential explanation for the effects of brain-damage on speech production errors in PWA. The authors provide a similar evaluation of the effect of age on the AP proportion with children producing a lower AP than adults. According to Dell, et al. "to the extent that low activation is caused by decreased weights, there should be a relative increase in perseverations." (p. 141). Or, conversely, as connection strength increases (e.g., learning, practice), the perseverative tendency decreases. Based on the model, the authors stated that anticipation errors also are less likely with increased connection weight, but the perseverative tendency is more greatly affected. Dell, et al. also make claims regarding the effect of speaking rate on production errors and these are discussed in the next section.

Individuals with aphasia do produce other types of sound-level errors that are not considered to be phonologic in origin because persons with aphasia frequently have concomitant motor speech disorders. These other sound-level errors are most readily and unambiguously identified as distortion errors and have been supported by perceptual, acoustic and physiologic investigations (McNeil & Kent, 1990). These methods have investigated production errors by examining a number of independent variables such as utterance length, stress and speaking rate; and dependent variables such as relative timing, inter and intra-segment durations, voice onset time and vocal reaction time. As argued by McNeil, et al. (1997) general characteristics such as inaccurately produced sounds, effortful, short-phrased speech, and decreased fluency are not distinctive among disorders and other types of errors (i.e., sound substitutions, omissions, additions) may be generated at either linguistic or motoric levels of the production system. The differential diagnostic value of sound sequencing errors is that they, as compared with other error types, can more confidently be attributed to disruption of the phonologic encoding (linguistic-symbolic) level of production (McNeil, et al.). The models of Dell (1986; 1988) and colleagues (Dell, et al., 1997) are consistent with this level of error assignment, however, they attempt to account for how serial order errors occur, and they propose variables such as the presence of aphasia and more precisely, changes of speaking rate, which may affect their likelihood of occurrence.

7.0 SPEAKING RATE RELATIVE TO PHONOLOGICAL ENCODING PROCESSES

Levelt (1989) specifies that speech rate is an important factor in phonological encoding because it “affects the size of phonological and intonational phrases” (p. 366) and “has consequences at the segmental and phonetic levels” (p. 366) of production. Levelt asserts that speaking rate affects the length of time that a node with the highest amount of activation maintains that level of activation and argues for the widespread effects of speaking rate at all levels of phonological encoding.

As previously stated (see the Models section), Dell (1986) incorporated predictions about the effect of speaking rate manipulations on phonological encoding in his speech production model. He proposed that speaking rate manipulations affect the amount of time available for spreading activation to activate the appropriate encoding units. He described how speaking rate might affect spreading activation such that predicted patterns of phonological serial order errors (i.e., anticipations, exchanges, perseverations) would occur. Dell was explicit that his model made no assumptions about whether speaking rate affected the rate of frame building or filling. According to Levelt (1989), “the rate parameter sets the speed of frame production at all levels of processing in phonological encoding” (p. 367).

Dell (1986) examined the effects of speaking rate through experimental simulations and through experiments with normal young adult participants. Dell, et al. (1997) extended speaking rate predictions to PWA, however, these predictions will be discussed later. Dell (1986) initially used computer simulations to evaluate his model's ability to represent phonological encoding behavior as detailed in the literature. Two computer simulations were conducted; the first simulation maintained a constant amount of spreading activation and spreading rate, while in the second, activation was allowed to vary. The value for the constant rate of activation was set for different processing functions (e.g., a certain rate for spreading vs. decay functions). In the first simulation, speaking rate and utterance length were manipulated as the computer simulation encoded word strings of one, two and six words at four different rates. The results were not surprising and provided evidence of the model's validity relative to normal phonological encoding. They revealed that longer word strings and faster rates produced more errors. Dell acknowledged some limitations of the model as in the simulation some utterances that violated rules relating to stress in English were encoded. Additionally, some phonological constructions not allowed in English also were produced. In the subsequent computer simulation designed to examine the types and frequencies of produced sound errors, variations in spreading activation levels were included during the encoding of word pairs at three speaking rates. In general, results revealed that the errors were similar to those reported in collections of normal slips of the tongue. These findings provided support for the processing assumptions in the model.

Based on assumptions regarding the behavior of spreading activation, Dell's (1986) model makes several predictions regarding various effects on sound errors (e.g., lexical bias, repeated phonemes, speaking rate). The predictions most relevant to this discussion are those regarding the effects of speaking rate on phonologic encoding and specifically on serial order sound-level (i.e., anticipation, perseveration and exchange) errors. Dell, et al. (1997) and Martin and Dell (2004) provide theoretical rationales for how and why each of these error types occurs. Martin and Dell highlight the fact that anticipation errors reflect speech planning as selection of the erred phoneme comes from speech not yet produced. They state that in order "for an anticipation error to occur, vulnerability of the current target word must co-occur with primed activation of a future target" (p. 351). Martin and Dell acknowledge the idea from Schwartz et al. (1994) and Dell, et al. (1997) that reduced activation strength contributes to an environment which is vulnerable to disruption. Martin and Dell state that this creates an environment "for any kind of intrusion because it alters the relative activation levels of the target word and other competing word and sound representations, including residual activation of words recently spoken and primed activation of planned utterances" (p. 351). Speaking rate and brain damage are variables that are associated with reduced connection strength (Martin & Dell, 2004). Strong connections are associated with an intact system and an intact system is future-oriented. Weak connections allow residual activation to have a greater affect on processing and leads to more perseverative errors. Dell (1986) predicted that anticipation errors are more likely to occur at slower speaking rates because the increased time for encoding allows the sound selected in error to be activated, have its activation decay and then re-bound to a high enough level to be re-selected in its appropriate location. At fast speaking rates an exchange error is likely to occur because activation from an anticipated sound does not have time to decay and rebound and thus cannot be chosen again for its intended location. Thus, whether or not a disruption in the encoding process is realized as an exchange error depends on the decay rate of the sound selected in error. Consequently, Dell predicted that the ratio of sound-level exchange to anticipation errors should decrease at slower speaking rates.

Martin and Dell (2004) proposed that speaking rate and brain damage also influence the occurrence of perseveration errors. Dell, et al. (1997) and Martin and Dell stated that faster speaking rates and brain damage result in less activated targets and make the assumption that brain damage reduces connection weights. No specific predictions are made relative to type of aphasia. According to Martin and Dell (2004) "for a perseveration error to occur, the current target's vulnerability must co-occur with persisting activation of a past utterance" (p. 351). These conditions are created if connection strengths are weak and if residual activation is sufficiently strong. Perseveration errors are more likely to occur at faster speaking rates because of the decreased amount of time between previously encoded units and current targets. Dell, et al. (1997) developed the anticipatory proportion (AP) metric which was defined as "the proportion of anticipation and perseveration errors that are anticipations" (p. 125). Based on the discussed theoretical assumptions, it was predicted that the AP proportion would be lower in faster speaking rate conditions and for brain-damaged participants. Experiments addressing these predictions regarding speaking rate and brain-damage will now be discussed.

Both Dell (1986) and Dell, et al. (1997) tested the effects of speaking rate manipulation on phonological serial order errors in young, normal language users. Dell (1986) randomly assigned 132 undergraduates to different speaking rate conditions. The stimuli were visually presented word pairs that appeared on a computer screen. Only word pairs that were cued were to be produced. The participants were required to produce experimentally manipulated word pairs within one of three specified time frames (500 ms, 700 ms, or 1000 ms). These time frames were defined by a deadline and indicated by an auditory tone. Speaking rate was manipulated by requiring participants to finish producing their productions before the tone sounded. The participants were given practice with their deadline condition. Production errors were coded and analyzed relative to several variables including error type. The results involving error types and speaking rate supported the model's predictions. There were significantly more speech errors at the faster speaking rate and significantly fewer errors at the slower speaking rate.

There was a significant interaction between exchange errors and other error types, with decreasing numbers (though not significantly different after the removal of incomplete exchange errors) of exchange errors occurring with slowed speaking rate. Thus, as predicted different error patterns resulted between faster and slower speaking rates. No data are presented for other serial order (i.e., anticipations, perseverations) sound errors patterns relative to speaking rate manipulation. In another study with similar methods, Dell (1990) investigated the effects of the grammatical status of a word (i.e., function or content) on the probability of serial error orders. Young normal language participants produced cued phrases in two different deadline conditions. While no significant results were obtained relative to the effects of grammatical status, significant results for error types were obtained between the deadline conditions. Significantly more exchange and perseveration errors were obtained in the shorter deadline (i.e., faster speaking rate) condition. This finding provided further support for the speaking rate predictions from the Dell (1986) model.

Vousden and Maylor (2006) conducted experiments that tested predictions from the model of Dell, et al. (1997), including predictions about the effects of speaking rate on serial order errors. In different experiments using the same or similar stimuli and methods, these investigators tested participants at different age ranges, including young children (eight to eleven years of age), young adults and older adults. In the experiments evaluating the effects of speaking rate, two groups of children, ages 8 years and 11 years, and young adults formed the participant groups. Relevant for this discussion, the speaking rate results revealed a significant effect of rate with more errors produced in the fast than slow speaking rates, however this was only true for the 11 year old age group. The authors determined that calculating the AP relative to speaking rate was not possible for the adult group as some participants did not make either anticipation or perseveration errors, particularly at the slow rate. Based on the overall pattern of performance they concluded that performance was consistent with a higher AP at the slower speaking rate for adults. Calculation of the AP with the two groups of children revealed no significant difference for AP with the 8 year old group, but a significantly lower AP at the faster rate for the 11 year olds. In a similar second experiment, younger (*M* = 21 years) and older (*M* = 72 years) adults were compared, however, many older adults were not able to perform the tongue twister task at the faster speaking rate and thus speaking rate AP ratios were not able to be compared for that group. Younger and older adults were not significantly different in the number of errors produced at the slow speaking rate. Young adults did produce significantly more errors at the fast than slow speaking rate. For the 16 out of 20 young adults for whom an AP was able to be calculated (across word and sound errors), a significantly lower AP was obtained at the fast speaking rate. Young and old participants did not produce a statistically significant AP difference in the slow speaking rate condition.

Further data regarding the effects of speaking rate manipulation on serial order sound-level errors were provided in a similar unpublished study (Fossett, McNeil, & Pratt, 2000). This study compared hypotheses from two different theoretical perspectives regarding the effects of speaking rate on serial order sound errors. One perspective was that of Dell (1986) which predicts an effect of speaking rate manipulation on phonologic encoding. The other perspective was proposed by McNeil & Kent (1990) and it asserted that manipulating speaking rate should selectively affect speech motor processes. Based on a review of the literature, these authors concluded that many production errors in pathological populations that were traditionally classified as linguistic level errors might actually result from movement level errors. They argued that while many speech error types can be generated at either a motor or a linguistic level of the production system, serial order phoneme errors may only be generated at the linguistic level and distortion errors only at the motor level. They suggested that the competence of the motor system could be examined by manipulating speaking rate, as this technique allows pre-motor variables (i.e., phonology) to remain constant.

In the Fossett, et al.(2000) study, 32 normal volunteers, 49-76 years of age, used a direct magnitude production procedure to produce three self-manipulated speaking rates (normal, fast and faster). Based on Dell (1986), it was predicted that the ratio of exchange/anticipation errors should increase with faster speaking rates. The stimuli consisted of auditorily presented word pairs and phonologically challenging (i.e., tongue twisters) sentences. As in Dell, word pairs consisted of interference, target and filler word pairs. Three to four interference pairs preceded a target word pair and were constructed such that the initial consonants of both words were in the reverse order of those in the upcoming target word pair. A tone signaled participants to produce the target word pairs. Both types of stimuli were randomized for presentation with the constraint that interference word pair sets and their related target word pair were kept together. The participants produced each stimulus item three times (once at each of the three speaking rates). The participants were instructed to respond immediately and vocal reaction time was measured, as longer response times might allow recoding of early phonological encoding or may allow changes in determining what information is immediately available to the motor plan, motor program, or execution processes. All productions were audio-taped and subsequently transcribed using broad phonetic transcription. Productions determined to be erred were narrowly transcribed. Errors were categorized using rules adapted from Dell (1986) and Dell, et al. (1997), with exchange and anticipation errors as the primary errors of interest. Results revealed that there were significant differences in the total number of errors produced among the three speaking rates for the phonologically challenging sentences, but not for word pair stimuli. There was a significant increase in the number of exchange errors from the typical to fast and typical to faster speaking rates, but not from the fast to faster speaking rates for the word pairs. For sentence stimuli, significant increases in the number of exchange errors were obtained from the typical to faster and fast to faster speaking rates, but not for the typical to fast speaking rates. There were no significant differences in the number of anticipation errors produced among speaking rates for word pair stimuli, however a significant increase was obtained for sentence stimuli between the typical and fast and typical and faster, but not fast and faster speaking rates. Results revealed no significant differences in the number of perseveration errors among speaking rates for word pairs, however, there was a significant increase between the typical and fast and typical and faster speaking rates. The authors reported that the results of many of the word pair analyses lacked power and thus should be interpreted cautiously. The results of the two-way ANOVA computed to examine the effects of speaking rate on the exchange/anticipation ratio revealed significant differences between the typical and fast speaking rates but not from the fast to faster speaking rates for the word pairs. For sentence stimuli, significant differences in the exchange/anticipation ratio were obtained from the typical to fast and typical to faster speaking rates, but not from the fast to faster speaking rates. In general, findings from this study supported the predictions of Dell (1986) and were interpreted as evidence that phonologic encoding can be affected by speaking rate. These findings were obtained despite several methodological differences with the experimental study conducted in Dell. Experimental differences included auditory and not visual presentation of stimuli, inclusion of sentence stimuli, older participants, and the use of a within group repeated measures design.

Schwartz, et al. (1994) designed a study to examine the effects of practice on speech production errors. Twenty young adult participants repeated 10 tongue twister phrases a total of 16 times each (two times in each of eight blocks) at a normal speaking rate. The speaking rate was controlled by an auditory and visual metronome. The stimuli were auditorily and visually presented preceding the first trial and then the visual stimulus was removed. The results revealed a significant increase in the number of anticipation errors with practice and a decrease in the number of perseveration errors. Thus, relative to the AP metric, results provided evidence for an increase in the AP with practice as the theory would predict; as practice is assumed to strengthen connections between processing units. Dell, et al. (1997) explored the nature of serial order in the speech production system relative to serial order errors and also hypothesized about the effects of practice and speaking rate based on the assumptions of the presented model. The participants were 41 young normal language speakers. The stimuli were novel tongue twister noun phrases, consisting of four content words. The utterances were produced at a normal speaking rate, controlled by a metronome. The results revealed that practice significantly reduced errors and increased the AP. This finding is consistent with the theoretical assumption that the uncompromised processing system is future oriented. In the theory, practice is viewed as affecting anticipation, but not perseveration errors because perseveration errors are related to the proposed turn-off function of the model and not the turn-on and priming functions that are associated with learning. Another experiment also examined the effects of both practice and speaking rate. It was predicted that a significantly greater AP ratio would be obtained at the slower relative to faster speaking rates. In this experiment participants produced a set of novel tongue twister (four word phrases) utterances at two different speaking rates, controlled by a metronome. The results revealed that both practice and speaking rate produced significantly fewer errors with more practice and at slower speaking rates. Additionally, the speaking rate manipulation affected the AP as predicted with a significantly lower AP ratio obtained at the faster speaking rate than at the slower speaking rate. The number of occurrences with both anticipation and perseveration errors increased in each practice block from the slow to faster speaking rate condition. Based on these findings, Dell, et al. (1997) predicted that the AP ratio would be lower in any error producing condition. These findings provide further support for the role of speaking rate manipulation in phonological encoding.

Kent and McNeil (1987) and McNeil, Liss, et al. (1990) examined the effects of speaking rate on motor level processing**.** Kent and McNeil (1987) examined the relative timing of sentence repetition in various speaking tasks, (e.g., different speaking rates, contrastive stress, multiple repetition) in two small groups of neurologically impaired participants (PWA and AOS) and in normal controls. The data were based on an acoustical analysis of two utterances produced at both a control and a fast speaking rate. The participants' productions were segmented into pseudosyllables and total and average segment and intersegment duration measures were made. Relative timing was also examined by determining the average percentage of the utterance that was contributed to by segment duration and examining intersegment-to-segment duration ratios. Other measures included a measurement of voice onset time across all speakers, for one word in one of the utterances and an examination of the formant trajectories across all speakers for one syllable in one of the utterances. This study reported data only on speaking rate tasks at the control and fast speaking rates. Descriptive measures revealed that despite a great deal of inter-subject variability, overall, normal participants reduced their segmental and inter-segmental durations with increasing rate to a greater degree than did either of the neurologically impaired groups. The persons with AOS produced substantively longer segment durations and demonstrated increased variability. The authors described segment duration data from PWA as comparable with that of the AOS participants in the fast speaking rate condition. Relative to intersegment durations, AOS participants produced substantively longer durations and, in general, greater variability than either the NBD or PWA groups. Intersegment/segment ratios were calculated and unlike NBD participants or PWA (in general), AOS participants sometimes (but not consistently) produced intersegment durations that were as extended in duration as their segment durations. The data from PWA were described as more variable than that of NBD participants. The amount of change between rates for segment and intersegment durations was also calculated and revealed that participants with AOS demonstrated a more restricted range of change than the other two groups. PWA performed more similar to the NBD participants. In general VOT measurements and formant trajectory data revealed similar findings regarding variability and the performance of PWA relative to NBD participants and AOS participants. Overall, results were interpreted to indicate an unambiguous motor level deficit for AOS participants. The performance of the PWA group was less clear as their performance often fell in between the other two groups. However, the authors concluded that PWA demonstrated some level of motor deficit. Importantly, however, they caution against any firm conclusions regarding the data on PWA due to the restricted number of participants on whom the data is based. The most consistent finding over all of the results was the variability demonstrated with AOS participants.

A study by McNeil, Liss, et al. (1990) replicated and extended the Kent and McNeil (1987) study in an effort to evaluate the effects of speaking rate on absolute and relative timing. A total of 8 participants, 3 with AOS, 2 PWA, and 3 NBD participants produced four utterances at three speaking rates. Acoustic and perceptual (including narrow phonetic transcription) analyses were completed on both erred and well-produced utterances. The results revealed that all participants produced the shortest and longest mean utterance durations at the fastest and slowest speaking rates respectively. NBD participants showed the most variability in utterance duration at the slowest speaking rate, while AOS participants demonstrated more variability at the control and fast speaking rates. The rate change for participants with AOS was decreased in magnitude relative to NBD and aphasics participants. Analysis of segment duration changes revealed that NBD participant, with rare exception, produced significant differences in the expected direction among all speaking rates. The participants with AOS produced significant differences primarily from the control – slow rate change. Neither group demonstrated significant differences in voice onset times (VOTs) among speaking rates. In general relative timing was consistent across speaking rate for NBD participants, but not for brain-damaged participants. Overall, results were interpreted to suggest that both groups of brain-damaged participants demonstrated motor control deficits. The results of both of these studies should be viewed cautiously as a small number of participants composed each group and the same individuals were used in both studies. These studies and those previously discussed do, however, support the idea that speaking rate affects both phonologic encoding and motor level processes with some differing consequences on the speech production system and on the specific errors generated. It is explicitly assumed that individuals with aphasia, as characterized in this review, do not have substantive deficits in post phonologic encoding processes. That is, those individuals included in this study were without a diagnosed motor speech disorder, based on specified criteria.

This review has revealed that some individuals with aphasia produce speech errors that can be characterized by errors of serial order. The language models of Dell (1986; 1988) and colleagues (Dell, et al., 1997) have attributed these serial order errors to the phonologic encoding level of production. Importantly, the relative frequency of the serial order errors is influenced by the presence of damage to the phonological encoding system, as well as by the task demands under which speech is produced; perhaps most importantly, the rate at which it is produced. While Dell and colleagues have generated a coherent model with which to account for serial order error types in normal and pathological speakers, they have not generated sufficient experimental evidence to support their claims that the mechanisms are applicable to PWA.

8.0 SUMMARY

The above discussion has outlined the differential contributions of the linguistic and motor-level processes to sound-level speech production. Because they make clear predictions about the different components of the linguistic architecture, the speech production process was placed within the frameworks of two general models. One detailed the production process from conceptualization to phonologic encoding and the other from phonologic encoding to the realization of an intended movement. Because it makes clear predictions about sound-level serial order errors, the most undisputed error type, belonging to the phonological encoding stage of speech production, the phonologic encoding process was primarily viewed within the theoretical framework of Dell (1986, 1988) and Dell, et al.(1997). This review discussed sound-level speech production errors relative to their frequency of occurrence and the variables that increase their likelihood (i.e., speech rate) in normal speech production and in persons with aphasia. Speaking rate was identified as a useful tool for manipulating the speech production system at both the phonologic and motoric levels with unique error types assignable to each level.

8.0 SUMMARY

8.1 STATEMENT OF THE PROBLEM

Evidence presented in this review suggests that speaking rate may be manipulated to affect phonologic encoding, as revealed by the proportion of sound-level serial order errors produced. Likewise, the experimental evidence assembled from normal participants (Dell, 1986; Fossett et al, 2000) suggests that speaking rate may influence the relative and absolute frequency of sound-level serial order error types. Preliminary evidence from PWA also supports this proposition. The models of Dell (1986; 1988) and Dell, et al. (1997) make explicit predictions about these relationships. The ability of speaking rate to affect phonologic encoding but not change motor level performance, as indicated by no significant differences between the number of distortion errors (errors that can confidently be attributed to a motor level of production) (McNeil, et al., 1997) produced between NBD participants and PWA at different speaking rates, suggests that phonologic encoding is time dependent and that processing within phonologic encoding can operate independently of motor level processes. Serial order errors that are produced without distortion are assumed to reflect disrupted processing at the phonologic encoding level of production. While the models and accumulated evidence are coherent with the notion that increased speaking rate can alter the frequency and proportion of serial order sound-level production errors in normal speakers, the data from carefully selected PWA are inadequate to judge the validity and generalizability of these findings or reify the predictions of the models for pathological speakers. This study sought to replicate these claims in persons with normal speech production and to evaluate them in PWA.

8.2 PURPOSE

Examining serial order errors in NBD participants and PWA will provide a direct assessment of the speaking rate predictions of the Dell (1986) model and will provide further evaluation of phonological encoding disruption in persons producing sound-level serial order errors. The purpose of this investigation was to address the following general question: Is there a significant difference in the relative proportion of specific serial order errors (anticipation to exchange and anticipation to perseveration errors) in NBD participants and PWA, across one typical and two increased speaking rates? This review has led to several primary and secondary experimental questions. The primary experimental questions are as follows:

8.2.1 Primary Experimental Questions

1. Is there a significant decrease in the ratio of anticipation to perseveration errors across the three self-manipulated increasing speaking rates, for the NBD participants and the PWA; and is there a significant interaction between speaking rate (normal, fast, faster) and participant group (NBD, PWA)?
2. Is there a significant decrease in the ratio of anticipation to exchange errors across the three self-manipulated increasing speaking rates, for NBD participants and

PWA; and is there a significant interaction between speaking rate (normal, fast, faster) and participant group (NBD, PWA)?

8.2.2 Secondary experimental questions

1. Is there a significant difference in the total number of sound errors (serial order, substitutions, distortions) produced by NBD participants and PWA among the three self-manipulated speaking rates (normal, fast, faster) and is there a significant interaction between speaking rate and participant group?
2. Is there a significant difference in the percentage of distortion errors among the three self-manipulated speaking rates (normal, fast, and faster) for NBD participants and PWA and is there a significant interaction between percentage of distortion errors and participant group?
3. Is there a significant difference in vocal reaction time among the three self-manipulated speaking rates (normal, fast, and faster) for NBD participants and PWA and is there a significant interaction between speaking rate and participant group?

8.2.3 Predictions

1) There will be a significant decrease in the ratio of anticipation to perseveration errors (AP) across the three self-manipulated increasing speaking rates, for the NBD participants and the PWA. There will be a significant interaction between speaking rate (normal, fast, faster) and participant group (NBD, PWA); with PWA producing significantly more perseveration errors than NBD participants at the faster speaking rate.

2) There will be a significant decrease in the ratio of anticipation to exchange errors (AE) across the three self-manipulated increasing speaking rates, for the NBD participants and the PWA. There will be a significant interaction between speaking rate (normal, fast, faster) and participant group (NBD, PWA), with a significantly lower AE at the faster rate for the PWA.
3) There will be significantly more total sound errors produced at each increased speaking rate (normal, fast, and faster) for both NBD and PWA groups. It is also predicted that there will be a significant interaction with PWA producing significantly more errors at each speaking rate than the NBD participants.
4) There will be a significantly higher percentage of distortion errors produced at each of the successive speaking rates for both the NBD and the PWA groups. No significant interaction is predicted.
5) There will be no significant difference in vocal reaction time across the three self-manipulated speaking rates (normal, fast, faster) for either the NBD or PWA groups. No significant interaction is predicted.

9.0 METHODS AND PROCEDURES

9.1 OVERVIEW

This study consisted of two separate training tasks and three experimental conditions. The training tasks served to familiarize participants with the demands of manipulating speech rate in order to meet a broadly specified internally determined speech rate. All training tasks were completed before the experimental conditions were administered.

9.1.1 Equipment

An Optimus portable CD player was used to present auditory stimuli for the *Picture Identification Task* (Wilson & Antablin, 1980), one of the auditory screening measures. EarTone 3A insert earphones were worn in all auditory criterion and experimental tasks. A Welch-Allyn otoscope was used in the performance of an initial otoscopic examination to determine if any counter-indicative (e.g., excessive ear wax, perforated ear drum, middle ear infection) conditions for insert earphone usage existed.

Data presentation and collection were performed on a Dell Inspiron notebook computer. Stimuli were presented using the E-Prime experimental environment (Psychology Software Tools, Inc.) through a MAICO MA 25 portable audiometer to control acoustic presentation level. A 55 dB (HL) presentation level was used unless a participant requested a higher level which was addressed during training tasks. A laptop computer and mixer connection allowed both stimulus and tone presentation to be recorded along with the participant's productions, so that vocal reaction time (VRT) and total duration (TD) measurements could be made. Additionally, the computer was connected to a response box with a voice-activated trigger. An Audio-Technica ATR355 Electret condenser omni-directional lavalier microphone was connected to the response box to activate the voice trigger when the participant began speaking. The participants' productions were recorded onto audiotape, using a Crown head-mounted miniature unidirectional condenser microphone (CM 312), positioned one inch from the corner of their mouth and connected to a TASCAM PORTA 02MKII mixer/recorder. The examiner monitored stimulus presentations from one channel of the portable audiometer to make sure that stimuli were presented as intended and that participants were responding to target stimuli and not fillers.

9.1.2 Training Task

In the first training task, four non-experimental, eight-syllable sentences were randomly presented twice, for a total of eight sentences at each rate. These sentences were constructed so as to be phonologically non-challenging. A 100 ms. pure-tone corresponded to the offset of the final acoustic energy in each phrasal stimulus. The participants were instructed to initiate repetition of each stimulus as fast as possible after they heard the tone and to produce the sentences at a typical speaking rate. The participants were then instructed to increase their rate using a direct magnitude production procedure (DMP) (described below). In order to familiarize participants with the task demands of immediately producing a stimulus after hearing the tone and to manipulate their speaking rate, they were instructed to make their speech even faster using the same practice stimuli. In addition to the auditorily presented instructions (See Appendix A), each participant was shown a visual scale consisting of a horizontal line 6 inches in length and bounded on each end by a ¼ -inch vertical line. The horizontal line represented the range of speaking rate. Another vertical line bisected the horizontal line and represented the typical speaking rate. There were two more vertical lines on the scale at locations previously determined to represent 45% and 95% of the scale and those percentages of speaking rate. The examiner pointed to each relevant marking to indicate the target rate at the appropriate time, in accordance with the auditorily presented instructions. This procedure was used for all tasks in which speaking rate was manipulated.

In a second training task participants were told to respond only when they heard a tone. The stimuli were the same four non-experimental, eight-syllable sentences used in the preceding training task. However, not every stimulus presentation was followed by a tone. The goal of this task was to train participants to respond only when they heard a tone as required in the experimental task. This task was completed only at the participants' typical speaking rate. Visual and verbal cuing was provided as necessary during both training tasks.

9.2 EXPERIMENTAL TASK

9.2.1 Stimuli

Stimuli consisted of 36 “tongue twister” sentences (12 experimental and 24 fillers) previously used in the Fossett, et al. (2000) study and adapted from previously published stimuli and from examples in children's literature (See Appendix B for a complete list of stimuli). Stimuli not followed by a tone were considered fillers.

All filler and experimental stimuli were seven or eight syllables in length. Sentence production difficulty was increased beyond that of the control sentences through by the presence of similar and repeating phonemes. All stimuli were digitally recorded at a sampling rate of 22 kHz by a male speaker, with previous experience in producing speech to meet specific acoustic parameters. Recordings were made in a sound treated environment at an approximate rate of three syllables per second. Stimuli were edited for duration and intensity using Superscope sound editing software on a MAC desktop computer. Experimental and filler sentence durations ranged from 3-4 seconds in duration. Sentence stimuli were equalized for amplitude (RMS) such that all syllables within each sentence stimulus sound file were within a 6 dB range of one another. In addition to the actual stimulus item duration, a 50 ms silent period was added to the beginning and end of each stimulus item and became part of the sound file for that stimulus item. After editing, a listener, unfamiliar with the stimuli, served as a judge of the intelligibility of all stimuli. This unfamiliar listener transcribed orthographically the words in each stimulus item after listening to them at a comfortable listening level through KOSS TD/80 headphones. Any items that were not identified accurately at a 100% level were re-edited for duration and intensity. The original sound files were deemed to be intelligible by the author and thus sound files were re-edited, not re-recorded. Re-editing consisted of replaying the original sound files, and re-making the previous duration and intensity edits. Following this, another unfamiliar listener made judgments regarding intelligibility. Again, any items that were not 100% accurately transcribed or which were deemed uncertain were re-edited. The 2nd unfamiliar listener and one new unfamiliar listener repeated the judging process independently. With 100% agreement from both judges, all stimulus sound files were then appropriately formatted and transferred to E-prime sound files.

9.2.2 Participants

Twenty NBD and 48 PWA were recruited into this study. Participants were obtained from existing databases and incoming patients at the University of Pittsburgh, the Pittsburgh VA Healthcare System, Moss Rehabilitation Research Center, Temple University, Philadelphia VA Healthcare System, Salt Lake City VA Healthcare System and the University of Maryland. Thirty-two participants (16 NBD (80% of those recruited), 16 PWA (33% of those recruited)) met the screening criteria. Two NBD recruits failed the hearing screening, one failed to meet *Revised Token Test* (RTT) (McNeil & Prescott, 1978) criterion, and one participant's data were not included due to equipment failure. Of the 48 PWA that were recruited, seven failed to pass the hearing screening, five were unable to repeat sentences, two did not pass the RTT criterion, one exceeded the criterion for the RTT for PWA, one failed to meet criterion for the *Coloured Progressive Matrices* (CPRM) (Raven, 1963), 12 were diagnosed with a motor speech disorder (nine with dysarthria, three with AOS), two had experienced more than one stroke (one of whom also did not meet the education requirement), one participant did not meet the age requirement (at the study's initiation, the minimum age requirement was 42 years), and one participant died in the interim between signing the consent form and scheduling his first experimental session. This participant's death was unrelated to this research study.

Sixteen NBD and 16 volunteers with aphasia met the inclusion/exclusion criteria. All participants were native speakers of English, over the age of 18, with at least 12 years of education. Table 1 presents demographic information for NBD participants and PWA. The NBD participants ranged in age from 41-75 years (M = 60; *SD* = 10.20). The PWA ranged in age from 36 - 77 years and had a mean age 56 (*SD* = 11.08) years. A one-way Analysis of Variance (ANOVA) revealed no significant difference in age between NBD participants and

PWA ($F_{1,31} = 1.39$, $p = .25$, $\eta^2 = .04$) (power = .20). The number of years of education for NBD participants ranged from 12 – 22 years with a mean of 16.38 years (*SD* = 2.45). Years of education for PWA ranged from 12 – 20 years with a mean of 15.19 years (*SD* = 2.34). A one-way ANOVA revealed no significant differences between the two participant groups in years of education ($F_{1,31} = 1.97$, $p = .17$, $\eta^2 = .06$) (power = .25). All participants were free from neuroleptics (not including antidepressants) and a history of substance abuse (alcohol and drugs), as determined by self-report. NBD participants were without a history or evidence of speech, language, cognitive, or neurologic deficits as indicated by self-report and measured by a large battery of standardized speech, language and cognitive tests (see Table 2) administered by a licensed and professionally certified speech-language pathologist. PWA met the criteria for the definition of aphasia as proposed by McNeil and Pratt (2001). This definition characterizes aphasia as a processing disorder that crosses all modalities and which is characterized by inefficiency in cognitive processing with resulting deficits in verbal-symbolic manipulations. For PWA, the neuro-radiological and medical reports related to the cerebrovascular accident were requested, though not always obtained.

Table 1: Demographic information for non-brain-damaged (NBD) participants and persons with aphasia (PWA)

NBD	Age	Education	PWA	Age	Education	Lesion Data (PWA)
1	63	14	1	51	14	L Posterior temporal; inferior left parietal
2	58	12	2	52	16	
3	75	18	3	65	16	
4	72	12	4	46	18	L MCA; L fronto temporal lobes
5	55	16	5	70	14	Periventricular white matter; chronic eschemic effect
6	67	16	6	70	16	L temporal and frontal
7	73	16	7	51	16	
8	72	16	8	52	20	
9	53	16	9	50	18	L fronto temporal extending to basal ganglia
10	66	16	10	60	12	

Table 1 (continued)

	11	62	18	11	66	16	
	12	56	16	12	53	12	L basal ganglia; posterior parietal
	13	49	18	13	45	12	L MCA distribution
	14	41	18	14	77	16	L posterior temporal-parietal
	15	53	18	15	36	13	Anterior and posterior L MCA and L putamen
	16	47	22	16	48	14	
M (SD)		60 (10.2)	16.38 (2.45)		56 (11.08)	15.19 (2.34)	

Note. Years of education represents a minimum number of years as some participants had completed additional education that did not result in another degree (i.e., post graduate work).

[a]L = Left; [b]MCA = Middle Cerebral Artery

Table 2: Participant Screening Measures

Picture Identification Task (Wilson & Antablin, 1980)

Coloured Progressive Matrices (Raven, 1963)

Immediate/Delayed Story Retell subtests from the *Arizona Battery for Communication Disorders in Dementia* (Bayles & Tomoeda, 1993)

55-item *Revised Token Test* (Arvedson, et al, 1986; McNeil & Prescott, 1978)

[a] Two-Item *Porch Index of Communicative Abilities* (DiSimoni, Keith, & Darley, 1980; Porch, 1981)

[a] *Boston Diagnostic Aphasia Examination* (Goodglass, Kaplan, & Barresi, 2001)

Subtests: Auditory Comprehension, Oral Expression Tasks, *Boston Naming Test* (Short Form)

Apraxia Battery for Adults (Dabul, 2000)

Subtests: Diadochokinetic Rate, Increasing Word Length, Limb Apraxia and Oral Apraxia, Repeated Trials)

Dysarthria Examination Battery (Drummond, 1993)

Tasks: S/Z Ratio, velar movement, Speech Intelligibility, Labial Movements, Mandibular Movement, Lingual Movements

Table 2 (continued)

Auditory Word Rhyme Judgment subtest from the *Psycholinguistic Assessments of Language Processing in Aphasia* (PALPA) (Kay, Lesser, & Coltheart, 1992)

Auditory Word Span, Phonologic Similarity and Word Length tasks (Waters, Rochon & Caplan (1992)

Note. [a]Study assessment measures administered only to PWA.

9.2.3 Screening Measures

Tables 3 and 4 present descriptive and screening measure data for both participant groups. All participants passed a pure tone audiometric screening at 30 dB HL, in at least one ear at .5, 1, 2, and 3 kHz and demonstrated word recognition scores above 67% on the *Picture Identification Task* (PIT) (Wilson & Antablin, 1980). PIT performance for NBD participants ranged from 92-100 percent (M = 98.75, SD = 2.41) and ranged from 86-100 (M = 96, SD = 4.92) for PWA. A one-way Analysis of Variance (ANOVA) revealed no significant difference in PIT performance between NBD participants and PWA ($F_{1,31}$ = 3.67, p = .07, η^2 = .11) (power = . 49). All participants demonstrated performance within the range of normal (above the 5th percentile with a total score greater than 15; the lowest score for normal older adults) on nonverbal reasoning skills as measured by the *Coloured Progressive Matrices* (CPRM) (Raven, 1963). The criterion for the CPRM was the same for both participant groups. CPRM percentiles are based on a normative NBD population of 60 – 89 years of age and the provided percentile data is for every five years, categorized by mean ages ranging from 65 – 85 years of age. CPRM performance ranged from the 25th – 95th percentile (*M* = 85.63, *SD* = 19.99) for NBD participants and the 50th – 95th percentile (*M* = 90.63, *SD* = 11.09) for PWA. A one-way Analysis of Variance (ANOVA) revealed no significant difference in CPRM performance between groups ($F_{1,31}$ = .77, *p* = .39, η^2 = .03) (power = .12). The Story-Retelling (immediate/delayed) subtest from the *Arizona Battery for Communication Disorders in Dementia* (ABCD) (Bayles & Tomoeda, 1993), a test of verbal memory, was administered to all participants. The immediate/delayed story-retell ratio (delayed recall/immediate recall X 100) exceeded a ratio greater than .70, indicating that the participants' delayed recall of story facts was not substantively diminished compared to their immediate recall of these same facts. The criterion for both participant groups was the same. NBD participants obtained ratios that ranged from 87.5 to 106.7 (*M* = 99.61, *SD* = 4.33) and for PWA, ratios ranged from 86.67 – 150 (*M* = 101.95, *SD* = .16.24). A one-way Analysis of Variance (ANOVA) revealed no significant difference in ABCD ratio between groups ($F_{1,31}$ = .31, *p* = .58, η^2 = .01) (power = .08). The NBD participants performed above the cutoff score of the 5th percentile for auditory language processing as measured by the 55-item version (Arvedson, McNeil & West, 1986) of the *Revised Token Test* (RTT) (McNeil & Prescott, 1978). RTT performance ranged from the 2nd to 100th percentile for NBD participants (*M* = 48.44, *SD* = 28.89) with overall mean scores that ranged from 13.83 – 15.00. The PWA obtained RTT overall mean scores that ranged from 8.31 – 14.13 with performance that ranged from the 2nd to 91st percentile (*M* = 74.50, *SD* = 25.75) for left-hemisphere brain damaged participants with aphasia. In addition to the above listed screening measures, PWA were also administered the two-item (shortened), version of the *Porch Index of Communicative Abilities* (SPICA) (DiSimoni, Keith, & Darley, 1980). The PWA obtained an overall score above 9.45 (estimated to be the 35th percentile) using the full 180-item PICA

(Porch, 1981) normative data for the left-hemisphere brain-damaged aphasic group. The PWA obtained overall mean scores that ranged from 11.43 – 14.21, and estimated SPICA percentiles ranged from 57 – 96 (*M* = 80.81, *SD* = 11.11). The PWA group was also administered subtests from the short version of the *Boston Diagnostic Aphasia Examination* (BDAE) (Goodglass, Kaplan, Barresi, 2001) as an additional descriptive measure. The BDAE word comprehension subtest scores ranged from 68 – 100 percent with a mean of 97.10 (*SD* – 8.03). All but one PWA obtained a score of 94 percent or above. Similarly, performance on the BDAE commands subtest ranged from 80 – 100 (*M* = 95.63, *SD* = 6.29) percent with all but one participant obtaining a score of 90 percent or above. Performance on the complex ideational material subtest ranged from 67 – 100 percent (*M* = 91.69, *SD* = 13.51). Subtests under the category of oral expressions produced similarly high percentage scores: Production of automatized sequences (i.e., days of the week, counting 1-10) (M = 98.94, SD = 4.25); Repetition of single words (M = 95.00, SD = 11.55); Repetition of short sentences (M = 90.63, SD = 20.16); and Naming (M = 97.50, SD = 4.47). The shortened version of the *Boston Naming Test (BNT)* (Kaplan, Goodglass & Weintraub (2001), administered as part of the BDAE, yielded a mean score of 81.5 (*SD* = 16.26) with a range of 40 - 100.

Table 3: Descriptive and screening measures for non-brain-damaged (NBD) participants and persons with aphasia (PWA)

Participant	[a]PIT Percentage		[b]RTT Percentile		[c]CPM Percentile		[d]ABCD [e]Ratio		[f]SPICA estimated percentile
	NBD	PWA	NBD	PWA	NBD	PWA	NBD	PWA	
1	100	86	35	2	75	90	100	100	79
2	100	100	75	90	95	95	100	100	77
3	100	98	14	46	95	95	100	129	66
4	100	100	59	88	50	95	106	108	88
5	100	98	3	89	90	95	100	87	92
6	100	100	68	90	95	95	107	100	70
7	92	98	59	36	90	90	100	89	57
8	100	100	50	79	95	95	100	100	72
9	100	100	74	89	90	95	100	100	91
10	98	100	2	60	25	95	88	100	71
11	98	90	79	88	95	90	100	88	96
12	94	96	38	91	95	90	93	100	82
13	100	86	14	90	95	95	100	89	89
14	100	92	62	90	95	95	100	100	91

Table 3 (continued)

15	100	98	47	78	95	90	100	92	83
16	100	96	100	86	95	50	100	150	89
M	98.75	96	48.69	74.50	85.63	90.63	99.61	101.95	80.81
(SD)	(2.41)	(4.92)	(29.01)	(25.75)	(19.99)	(11.09)	(4.33)	(16.24)	(11.11)

[a]PIT = *Picture Identification Task* (Wilson & Antablin, 1980); [b]RTT = *Revised Token Test* (McNeil & Prescott, 1978), percentiles for NBD participants are based on normative data from a NBD sample while percentiles for PWA are based on normative data from a sample of PWA; [c]CPM = *Coloured Progressive Matrices* (Raven, 1963); [d]ABCD = *Arizona Battery for Communicative Disorders of Dementia*, Immediate to Delayed Story Retell Performance (Bayles & Tomoeda, 1993; [e]ABCD Normative Data (Bayles, Boone, Tomoeda, Slauson, & Kaszniak, 1989); [f]SPICA = *Shortened Porch Index of Communicative Ability* (DiSimoni, Keith, & Darley, 1980).

Participants with counter-indicative otoscopic (e.g., excessive ear wax, perforated ear drum, middle ear infection) results were not permitted to participate in the study. Subtests from the *Apraxia Battery for Adults -2* (ABA) (Dabul, 2000) and the *Dysarthria Examination Battery* (DEB) (Drummond, 1993) were administered to all participants to elicit behaviors from which the presence of motor speech disorders (i.e., apraxia of speech and dysarthria) were judged. Participants who presented with dysarthria or AOS were excluded from participation. The presence of dysarthria was judged perceptually by the examiner, a licensed and certified speech-language pathologist and subsequently confirmed by another licensed and certified speech-language pathologist experienced in the diagnosis of motor speech disorders. These judgments included speech and voice characteristics that have been determined to contribute to the diagnosis of a motor speech disorder (Darley, Aronson & Brown, 1969a; Darley, Aronson, & Brown, 1969b). Criteria for determining the presence/absence of AOS was also based on characteristics defined by McNeil, et al. (1997), and included the following: prolonged vowel and consonant durations in multisyllabic words, increased intersegment durations, and the presence of sound-level distortions, (including distorted perseverative, anticipatory and exchange phoneme errors) and distorted sound substitutions. Speech produced during the speech motor assessment tasks was used to make these judgments.

Auditory word rhyme judgment, word span, phonologic similarity and word length tasks were administered to all participants to provide descriptive measures of phonologic processing and working memory span. The auditory word rhyme judgment task consisted of word pairs from the auditory word rhyme judgments subtest of the *Psycholinguistic Assessments of Language Processing in Aphasia* (PALPA) (Kay, Lesser, & Coltheart, 1992). Participants indicated whether items in a word pair rhymed by pointing to yes/no response cards, with a verbal response, or head gesture. The NBD participants obtained a word rhyme mean percentage correct of 98.56 (*SD* = 1.46) while PWA obtained a mean percentage correct of 95.19 (*SD* = 5.69). A one-way Analysis of Variance (ANOVA) revealed a significant difference in auditory word rhyme judgment performance between NBD participants and PWA ($F_{1,31} = 5.27$, $p = .03$, $\eta^2 = .15$). However, eight of the sixteen PWA scored within 1 SD of NBD participants on this measure.

The auditory word span, phonologic similarity and word length tasks described by Waters, Rochon and Caplan (1992) were administered to all participants. The stimuli for these tasks were those developed by and borrowed from Waters et al. and included line drawn pictures of presented stimulus items. The words were audio recorded and presented at a rate of one item per second and no stimulus item was repeated within a memory span size. In this task, each participant was presented with ten trials at each span size from two to nine words (80 maximum trials). Auditory word span was determined by the largest span size at which correct and correct serially ordered performance was demonstrated for six of the 10 trials. No trials at succeeding span levels were given once a participant failed to respond accurately to six of the 10 trials at the current span. This task determined the word-span level at which the phonological similarity and word length tasks were administered for each individual participant. As suggested by Waters et al., this method allowed all participants to be tested at a comparable word span level. After each stimulus trial, the participants responded by pointing to the randomly ordered, pictorial representations of those items in correct sequential order. A pointing response was used because verbal responding might have been compromised by production errors (i.e., lexical, phonological). Following the methods and scoring procedures used in Waters et al., the participants were required to respond by pointing to the same items and to the same number of items that were presented.

The NBD participants demonstrated auditory word spans ranging from four to six words with a mean of 4.88 words (*SD* = .72). Thirty-one percent (five) of NBD participants demonstrated an auditory word span of four words, 50% (eight) a span of five words, and 19% (three) a span of six words. The group with aphasia obtained auditory word spans that ranged from two to five words with a mean auditory word span of 3.38 words (*SD* = .81). An auditory word span of two was obtained by two (13%) PWA. Forty-four percent (seven) of the PWA obtained an auditory word span of three. A span of four was obtained by 38% (six). One (6%) PWA obtained an auditory word span of five. A one-way Analysis of Variance (ANOVA) revealed a significant difference in auditory word span between NBD participants and PWA ($F_{1,31}$ = 30.86, p = .00, η^2 = .51).

The phonological similarity word-span task used sequences of phonologically similar words (e.g., mat, fat, pat, cat, etc.) and the word length tasks used short (one syllable) (e.g., van, jug, paw, tub, etc.) and long (three syllables) words (e.g., telescope, magazine, skeleton, computer, etc.) that were not phonologically similar to one another. Items in each task were derived from a core set of eight words specific to that task. Administration of each of these tasks began at the highest span level obtained on the auditory word span task. The auditory word span task was always presented first and the lowest word-span level available on that task was three words. Thus, the three word span level was the minimum span level at which the phonological similarity and short and long word tasks could be administered. Methods, procedures and criteria for these tasks followed those of the auditory word-span task. On the phonological similarity word-span task, the NBD participants obtained a mean word-span of 3.31 (*SD* = .48). Sixty-nine percent (eleven) of the group obtained a phonological similarity word span of 3 words while 31% (five) obtained a span of four words. Nineteen percent (three) of PWA obtained a mean phonological similarity word span of three, with each of those three obtaining a phonological word span of three (SD = 0). Seventy-five percent (twelve) of the PWA had a word span less than three; the lowest phonological word span level measured in this task, thus a mean and standard deviation could not be calculated for these participants. One participant (six percent) had missing data and three (nineteen percent) participants had a word span of three for this span task. Results from a Mann Whitney U test revealed significant differences (Z = -4.68, p = .00), between these groups.

For the word length short task, NBD participants demonstrated a word span range of three to six words with a mean word length short word span of 4.56 (*SD* = .81). For NBD participants, six percent (one) obtained a short word length span of six, 56% (nine) a span of five, 25% (four) a span of four, and 13% (two) a span of three. The PWA demonstrated a range from below three (the lowest word span level measured for this task) to four words with a mean of 3.17 and a SD of .39 on this task. Four (25%) PWA yielded a short word length span of less than three (the minimum span level available for measurement in this task). Nine (56%) demonstrated a short word length span of three and two (11%) obtained a span of four. One participant (six percent) had missing data for this span task. Results from a Mann Whitney U test revealed significant differences (*Z* = -3.72, *p* = .00), between groups.

For the word length long span task, NBD performance ranged from a three to five word span with a mean span of 3.81 (*SD* = .75). Thirty-eight percent (six) of NBD participants obtained a word length long span of three, 44% (seven) a span of four and 19% (three) a span of five. The span for the PWA reached a maximum of four, ranging from less than three to four, with a mean of 3.1 and a SD of .32. Thirty-eight percent (six) demonstrated a word length long word span below three (the minimum word span level available for measurement in this task), while 56% (nine) obtained a word length long span of three and one (six percent) obtained a span of four. Results from a Mann Whitney U test revealed significant differences (*Z* = -2.6, *p* = .01), between groups. In summary, as expected, for all of the word span task results, PWA performed significantly more poorly than NBD participants. Table 4 summarizes the descriptive measures for auditory word rhyme judgment, word span, phonologic similarity and word length (short and long) tasks that were administered to provide a description of phonologic processing and working memory for both NBD participants and PWA.

Table 4: Descriptive measures of phonologic and working memory span for non-brain damaged (NBD) participants and persons with aphasia (PWA)

Participant	[a]Rhyming Percentage		[b]Auditory Word Span (n of words)		[b]Phonological Similarity Span (n of words)		[b]Word Length Span			
							Short (n of words)		Long (n of words)	
	NBD	PWA	NBD	PWA	NBD	PWA	NBD	PWA	NBD	PWA
1	97	98	5	3	4	<3	5	<3	5	<3
2	100	98	5	5	3	3	5	4	4	3
3	100	97	4	2	3	<3	4	<3	3	<3
4	100	92	4	3	3	<3	3	<3	3	<3
5	100	95	6	3	3	3	5	3	4	3
6	98	81	4	4	3	<3	4	4	4	3
7	100	100	4	3	3	<3	3	<3	3	<3
8	96	98	5	3	3	<3	5	3	4	<3
9	100	100	5	4	3	3	5	3	4	4
10	96	96	4	3	3	<3	4	3	3	<3
11	98	100	6	4	4	<3	5	3	5	3
12	98	96	5	3	3	<3	4	3	3	3
13	98	96	5	2	4	<3	5	3	4	3
14	98	100	5	4	3	<3	5	3	3	3

Table 4 (continued)

15	100	98	6	4	4	[c]MD	5	[c]MD	5	3
16	98	83	5	4	4	<3	4	3	6	3
M	98.56	95.50	4.88	3.38	3.31	[d]3.0	4.56	[d]3.17	3.81	[d]3.1
(SD)	(1.41)	(5.52)	(.72)	(.81)	(.48)	(0.0)	(.81)	(.39)	(.75)	(.32)

Note. < preceding a data value indicates performance below criterion for smallest stimuli set. [a]Auditory word rhyme judgment task (Kay, Lesser, & Coltheart, 1992); [b]Auditory word span tasks (Waters, Rochon & Caplan, 1992); [c]MD = Missing Data.

9.2.4 Experimental Procedures

Each participant was evaluated individually in a quiet room, either in the university laboratory, at the hospital or nursing care facility, or in the participant's home. Participants required one to five sessions to complete the protocol. All protocols were completed within two weeks and all but two participants (both brain-injured participants) within 3 sessions. For most participants, both PWA and NBD, the protocol was completed in about 3 ½ hours. At study completion, the participants were paid $40. Participants were paid $10, who signed a consent form and attempted, but did not pass initial screening measures in which immediate judgments regarding task success could be made.

The experimental task consisted of three speaking rate conditions: typical, fast and faster. Participants were presented with 12 experimental and 24 non-experimental, phonologically challenging sentence stimuli at each of the three speaking rates. Instructions were auditorily presented from the computer immediately preceding each stimulus rate condition. The visual scale was used again to help convey the concept of rate manipulation. As in the training tasks, a 100ms, 1000 Hz tone followed all stimuli that were to be produced and participants were asked to begin their responses as quickly as possible after hearing the tone. The examiner controlled the inter-stimulus presentation rate to allow for anticipated variability in production time among participants. The sentences were presented randomly and the condition order was counterbalanced across participants. A short break (2 min.) was provided after every 36 trials and before instructions to produce the stimuli at the next rate. (See Appendix A for instructions). Both verbal (e.g., “go a little faster”) and non-verbal cues (i.e., pointing to the appropriate mark on the visual scale used in training) were used to encourage rate compliance, as necessary, during data collection.

9.2.5 Soundfiles and Digitization

Audio recordings of the participants’ productions were digitized in the Computerized Speech Laboratory (CSL) (Kay Elemetrics) main program at a sampling rate of 25,000 Hz. The recordings were played from a Marantz PMD 360 into the CSL. The examiner monitored the sound digitization process by listening to the sound files through headphones. The soundfiles were re-played from the CSL through the headphones to make sure the correct sound file had been captured. Only the target productions (productions of stimuli that were followed by a tone) were digitized. The sound files were digitized from the beginning of the tone through the end of the participant’s production with an allowable maximum sample length of 12 seconds. Sound files were captured from the beginning of the tone to 1 second post-production for the sound file. If one second was not available, the examiner recorded as long as possible to make sure that no part of the signal was deleted. The stimulus also was digitally captured so that if a participant's production was unintelligible during later analysis, the target for the production was evident. The input intensity of the signal from the tape recorder to the CSL was monitored to limit peak clipping of the signal as indicated by the recorder VU meter. Because the intensity of the sound file varied over the course of productions consistent monitoring was necessary.

9.2.6 Data Organization

The predictions for the phonological error ratio research questions addressed in this study are based on assumptions about the time-course and behavior of the mechanism of spreading activation and the phonological error proportions are predicted to change as the result of changes in speaking rate. For this reason, participant responses collected from each rate condition were re-categorized to reflect actual production speaking rate rather than categorized according to the instructed speaking rate for that sentence. That is, a participant may have produced a given response for a given stimulus at a specified rate condition, at a speaking rate other than the target rate. For example, a sentence may have been produced at the "typical" speaking rate even though the instructions were to speak at the "faster" speaking rate. In these cases, the produced sentence was re-categorized and placed with other sentences that were produced at the same realized rate (i.e. moved to the category with other "typical" tokens). The determination of a "typical" and a "fast" speaking rate was based on the mean plus one standard deviation of the speaking rate for tokens produced relative to the instructed rate condition (that is, without any re-categorization of tokens). It was assumed that because the "typical" speaking rate condition did not demand any adjustment from the participant's normal speaking rate, productions produced at this rate would likely be representative of the participants "typical" rate. Thus any tokens produced up to the mean plus one standard deviation of the “typical” speaking rate, regardless of the conditions at which the token was originally elicited, were categorized as “typical.” Tokens with a speaking rate above the mean plus one standard deviation of the originally categorized “typical” speaking rate up to one standard deviation about the mean plus one standard deviation of the originally categorized “fast” speaking rate were categorized or re-categorized as “fast” tokens. Any tokens that exceeded the mean plus one standard deviation of the original fast rate were categorized or re-categorized as “faster” tokens.

9.2.7 Transcription and Transcription Reliability

All utterances were transcribed by the examiner with broad phonetic transcription, but utterances perceived to be distorted were narrowly transcribed using the phonetic transcription categories of Shriberg and Kent (1995). Inter- and intra-rater reliability was obtained on a portion of all productions See Appendix C for further details regarding transcription procedures and data reliability. In general, intra –rater reliability transcription yielded point-to-point reliability ranging from 50% - 100% for NBD participants and 58% – 100% for PWA. Inter-rater reliability results yielded point-to-point reliability ranges from 55% - 100% for NBD participants and 55% - 95% for PWA.

9.2.8 Error Coding and Error Coding Reliability

Subsequent to phonetic transcription, sound production errors were coded for type of error. Coding categories included the following: anticipation, perseveration, exchange, distorted anticipation, distorted perseveration, distorted exchange, sound distortion (approximation of target sound), sound substitution (replacement of a single phoneme with a sound not contained in the target), distorted sound substitution, sound addition, sound deletion, ambiguous, whole word anticipation, whole word perseveration, whole word exchange, whole word substitution, and non-word. See Appendices D and E for guidelines and definitions of these error categories. Errors other than anticipations, perseverations and exchanges were coded for descriptive purposes. Inter- and intra-rater reliability was obtained on a portion of the data. See Appendix F for further error coding details and Appendix G for error coding reliability results. In general, the percentage of agreement at each speaking rate for NBD participants regardless of error type was 100% and for PWA it ranged from 67% - 77% with an average of 71%.

9.2.9 Phonological Error Opportunities

To determine the proportion of phonological error types produced, it was necessary to first determine the number of opportunities for each serial order phonological error type (i.e., anticipations, perseveration, and exchanges) to occur within a target sentence. To do this, each sound from each phonetically transcribed target sentence was judged as to whether or not that sound could replace any other sound in the sentence or change positions with the other sounds and not violate the phonotactic rules of American English (e.g., a target schwa sound could not replace a vowel in a stressed syllable, because the schwa sound only occurs in unstressed syllables). See Appendix H for the guidelines and rules used to determine phonological error opportunities.

Table 5 presents the error opportunities (potential errors) in each of the 12 target stimuli for each phonological error type (i.e., anticipations, perseverations, exchanges).

Table 5: Phonological error opportunities (anticipations, perseverations, exchanges) in target stimuli

Stimuli	Anticipation Opportunities	Perseveration Opportunities	Exchange Opportunities
A blinding blizzard blew briefly	34	30	19
The grouchy group groaned gloomily	41	37	26
Frightened Fred fries fresh flour	27	17	31
The flighty fleeing flea flew free	23	9	10
Glenda’s gleaming glove glimmered green	44	49	37
Brad bravely broke Brooke’s brittle blades	49	37	37
The grim grizzly grabbed grimy glue	46	25	18
Frank fried fragrant frozen flounder	36	34	32
The classy clown cleaned clay crabs	41	22	20
Gleeful Glenn glued the glass grape	55	38	48
Flopping Flipper flipped friskily	34	25	16
Brawny Brett’s brilliant bride blinked	47	24	20

9.2.10 Acoustic Measurement

Measurements were made using two screen views, a wide-band spectrogram (286 Hz bandwidth) and the waveform. The signals were displayed on a Super VGA 800X600 monitor with 640X480 pixels. The screen viewing size was adjusted as necessary to allow for precise measurement. For spectrographic analysis, a frame length of 125 (bandwidth 286 Hz) was selected with the pre-emphasis option chosen. Other settings included Blackman window weighting, a darkness scale of 14 and the gain adjustment set to one. Information from both the wave and the spectrogram were used to guide measurement decisions. Two measurements were made from these data: vocal reaction time and total duration. Vocal reaction time was defined as the time from the offset of the beep to the initiation of sound production. Total duration was defined as the time from the initiation to termination of production of the experimental sentence. Inter- and intra-rater reliability was obtained on a portion of all data. See Appendix I for further information regarding guidelines and procedures for acoustic measurement. Overall, both inter- and intra-rater reliability for the VRTs across all three speaking rates yielded Pearson and Spearman Rho correlation coefficients that ranged from .97 – 1.0. For syllables per second the inter- and intra-rater reliability across all three speaking rates ranged from .98 – 1.0. See Appendix J.

For a response to be eligible for acoustic analysis it had to contain the same number of syllables as the target, be without false starts (e.g., beginning the sentence and then stopping and restarting), speech interruptions (i.e., “um”), or non-speech interruptions (i.e., coughs). Productions in which the word “something” was substituted for target words in the sentence were not eligible for acoustic analysis or error coding. Productions containing non-words, phonological errors and distortions were included as long as they met other inclusion criteria.

9.2.11 Vocal Reaction Time (VRT) measurements

To facilitate reliable measurements, guidelines for the measuring the duration of the signals in the waveform and spectrographic windows were developed. The judges adjusted the displayed signal such that approximately 100 ms before the tone and 100 ms following the initiation of the speech signal were visible. The VRT measurements were made from the beginning of the tone to the initial sound in the utterance and were based on guidelines provided in Kent and Read (1992). The 100 ms duration of the tone was subtracted for the reported VRT measurement. For initial stop consonants, measurements were made to the burst. Judgments for determining the beginning of a fricative were based on the presence of a noise segment above 40 dB. The criteria for determining the beginning of a nasal consonant included the identification of a nasal murmur reflected in the acoustic signal by high amplitude of the low-frequency resonance. Formant and transition patterns were used to guide judgments of the initiation of a glide consonant. Steady state and transition patterns were used to guide judgments about the initiation of liquid consonants. Productions beginning with a vowel were measured from the beginning of the tone to the first glottal pulse. Total utterance duration measurements were made from the first identifiable segment of the target's initial phoneme, to the last recognizable segment of the utterance's final sound, based on the previously stated criteria. Aspiration noise with final stops below 40 dB was not included in the total duration measurement. Final judgments for measurement accuracy were typically based upon the spectrograph as opposed to the waveform. Additionally, perceptual judgment was used when visual inspection of the spectrograph and waveform yielded uncertain measurements. Average syllables per second (syll./sec.) were calculated by dividing the number of syllables by total duration time. See Tables J1 and J2 for inter- and intra-rater reliability data for the VRT measurement. See Table J5 for inter-rater reliability differences in ms. for VRT. In general, for VRT the average difference between raters in ms. ranged from .000 - .008 ms. which represented zero to one percent of the mean.

9.2.12 Total Duration (TD) measurements

The total duration of the signal in the waveform and spectrograph windows was limited to approximately 1 second. To facilitate reliable measurements when signal termination was unclear, judges identified a 300 ms period of time within which they determined that the signal had ended. They then calculated an energy spectrum to identify the last point at which signal noise was above 40 dB and marked that point for signal termination.

9.2.13 Syllables per Second (syll./sec.)

The syllables per second metric was calculated by dividing the number of syllables in each stimulus by the total duration of the response. See Tables J3 and J4 for inter- and intra-rater reliability data for the syll./sec. measurement. See Table J6 for inter-rater reliability differences in ms. for syll./sec.. In general, for syll./sec. the average difference between raters in ms. ranged from .000 - .008 ms. which represented zero to one percent of the mean.

10.0 RESULTS

10.1 ANALYSES

Statistical analyses were computed using SPSS for Windows 14.0 statistical package. Two-way repeated measures ANOVAs were computed to examine main effects and interactions of speaking rate and group for the anticipation and exchange proportion, the anticipation and perseveration proportion, VRT, total number of errors and percentage of distortion errors. Data were first examined to determine if they met the normality assumption**.** The independent variable of speaking rate (normal, fast, faster) was the within group variable and participant group (NBD, PWA) was the between groups independent variable for each of the dependent measures contrasted. An alpha level of .05 was chosen for all comparisons and a Bonferroni adjustment for multiple comparisons was used to compute post-hoc comparisons. Results of a power analysis based on speech sound error data from NBD participants obtained from an unpublished study (Fossett, et al., 2000) suggested that 16 participants in each of the two participant groups would be necessary to obtain a power of .8 and an effect size of .4.

For experimental questions one and two it was necessary to determine error proportions for specific phonological error types. An arcsine transformation was calculated to normalize ratios formed from the number of errors for each error type (anticipations, exchanges, perseverations) relative to the number of opportunities for that type of error to occur. An averaged arcsine transformation value (averaged across the 12 experimental sentences) was obtained for each participant for each of the three error types. The transformed values were then used to form ratios for the specified error type ratios (anticipation:perseveration (AP), anticipation:exchange (AE)). For example, to form the AE ratio, the arcsine transformed value for anticipations was divided by the arcsine transformed value for exchange errors (see Table 9). The resulting values for each specified error type ratio were then entered into a two-way ANOVA.

10.1.1 Missing Data

Five-hundred-seventy-six sentences from each of the two participant groups (1,152 total sentences) were potentially eligible for data analysis. After removing those sentences that were produced with the wrong number of syllables, with false starts and/or containing speech interruptions, 69% of the productions from NBD participants (399/576) and 27% of the productions from PWA (157/576) remained for acoustic and perceptual analyses**.** See Table 6 for total number of re-categorized sentences for NBD and PWA at each speaking rate.

Table 6: Total number of re-categorized sentences for non-brain damaged (NBD) participants and persons with aphasia (PWA), at each speaking rate

	NBD			PWA		
Participant	[a]Typ	Fast	Faster	[a]Typ	Fast	Faster
1	10	17	2	[b]	1	[b]
2	6	17	6	7	16	3
3	14	[b]	2	1	1	0
4	9	9	7	1	5	1
5	10	3	6	1	1	1
6	7	13	4	11	7	2
7	4	5	0	7	1	3
8	10	8	5	9	4	4
9	7	16	2	4	4	2
10	9	11	3	0	0	0
11	8	18	6	2	2	2
12	6	15	5	5	0	0
13	9	15	4	0	3	0
14	10	10	11	1	1	1
15	10	16	5	10	6	3
16	10	12	7	7	10	7
Total	139	185	75	66	62	29
Grand Total	399			157		

Note. [a]Typ = Typical; [b] = Missing Data

10.1.2 Data Description

In order to describe the error data produced in this experimental study, a number of sound and word categories were developed. Appendix K, Tables K1 – K6 summarize descriptive data for all error categories, at each speaking rate, for both participant groups.

The serial order error ratios computed for the two primary experimental questions in this study were formed by proportions from three different error types. Figures 1 and 2 present the pattern of performance on each of the error types by NBD participants and PWA, respectively, at each of the three speaking rates. Tables 7 and 8 summarize data for the numbers of each serial order type error produced by each NBD participant and PWA respectively, at each speaking rate. The mean percentage of errors (number/opportunity) for anticipations at each of the three increasing speaking rates was, .5%, .9% and 1.2%, respectively for NBD participants. For exchange errors the means were .2%, .2% and .4%, respectively. The mean percentage for perseveration errors was .3%, .5% and .2% from the typical to fast to faster speaking rates. The means for anticipation errors for PWA at the typical, fast, and faster speaking rate were 1.0%, 1.0% and 1.3%. For exchange errors the mean percentages were 0.8%, 0.3% and 0.2% and for perseveration errors, 0.2%, 0.1% and 0.2%, respectively.

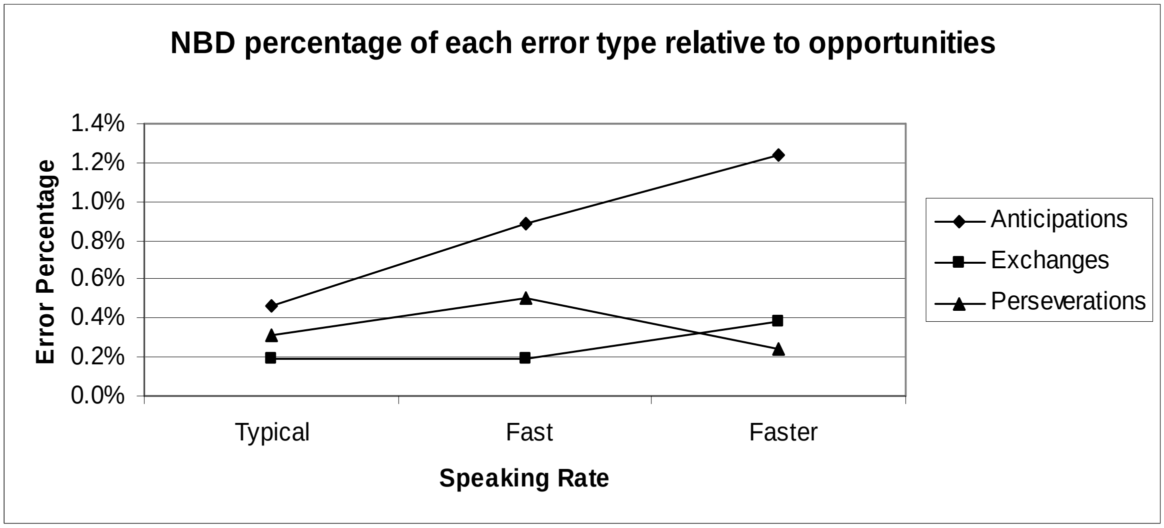

Figure 1: Percentage of each error type relative to the opportunities for the error to occur for non-brain damaged (NBD) participants

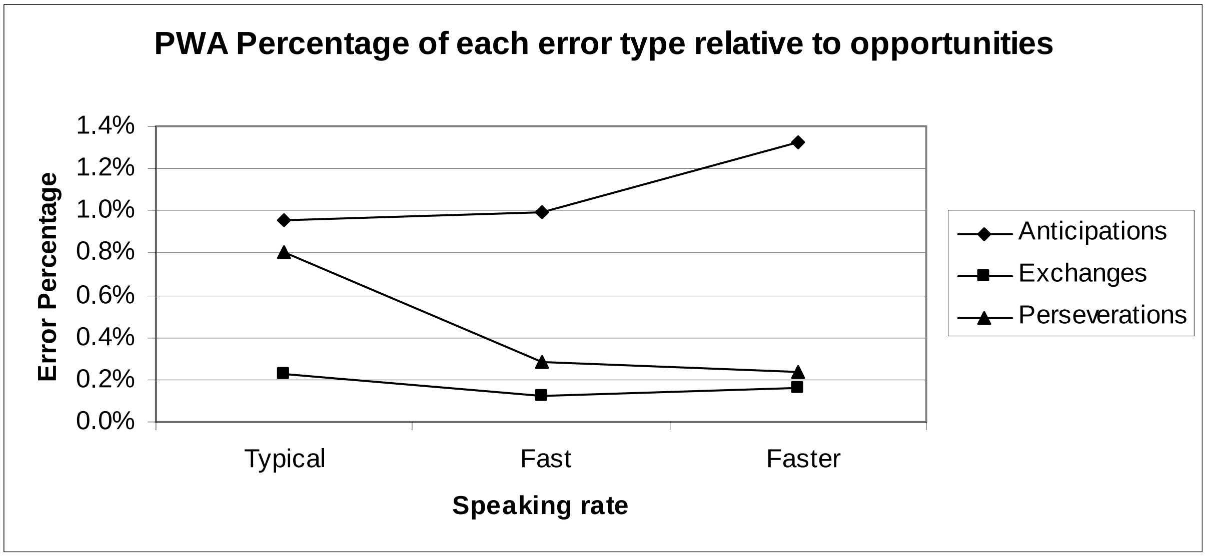

Figure 2: Percentage of each error type relative to the opportunities for the error to occur for persons with aphasia (PWA)

Table 7: Numbering, average, and standard deviation of anticipation, exchange and perseveration errors for each non-brain damaged participant at each speaking rate

Participant	Typical			Fast			Faster		
	[a]Ant	[b]Exch	[c]Persev	[a]Ant	[b]Exch	[c]Persev	[a]Ant	[b]Exch	[c]Persev
1	2	0	1	4	0	0	0	0	0
2	0	0	0	6	4	1	3	1	1
3	3	1	1	[d]	[d]	[d]	1	0	0
4	5	0	0	4	0	1	8	0	0
5	1	0	1	0	0	0	1	2	0
6	2	0	0	14	1	1	3	1	0
7	1	0	0	1	0	0	0	0	0
8	1	0	0	2	0	0	1	1	0
9	1	2	0	8	0	3	2	1	0
10	3	1	4	3	0	1	3	0	1
11	2	0	0	4	1	7	3	0	0
12	2	1	2	8	1	6	4	0	1

Table 7 (continued)

13	0	1	2	4	0	1	0	0	0
14	1	1	1	3	1	1	5	1	2
15	2	0	0	1	1	2	1	0	0
16	0	0	0	2	0	1	1	0	0
Total errors	26	7	12	64	9	25	36	7	5
Mean	1.63	0.44	0.75	4.27	0.60	1.67	2.40	0.47	0.33
SD	1.31	0.63	1.13	3.58	1.06	2.13	2.13	0.64	0.62

Note. [a]Ant = Anticipation; [b]Exch = Exchange; [c]Persev = Perseveration

Table 8: Number, average, and standard deviation of anticipation, exchange and perseveration errors for each person with aphasia at each speaking rate

Participant	Typical			Fast			Faster		
	^{a}Ant	^{b}Exch	^{c}Persev	^{a}Ant	^{b}Exch	^{c}Persev	^{a}Ant	^{b}Exch	^{c}Persev
1	0	0	0	1	0	0	0	0	0
2	0	1	2	9	0	1	0	0	1
3	0	0	0	0	0	0	0	0	0
4	0	0	0	2	0	0	3	0	0
5	1	0	0	0	0	0	0	0	0
6	4	0	3	1	0	1	0	0	0
7	2	0	1	0	0	0	1	0	1
8	7	0	5	1	0	0	3	0	0
9	1	0	0	3	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0
11	0	0	0	1	0	0	0	1	0
12	1	0	0	0	0	0	0	0	0
13	0	0	0	0	0	1	0	0	0
14	0	1	0	1	0	0	0	0	0
15	6	2	2	1	1	0	3	0	0
16	3	0	1	5	1	2	4	0	0

Table 8 (continued)

Total errors	25	4	14	25	2	5	14	1	2
Mean	1.92	0.31	1.08	1.79	0.14	0.36	1.27	0.09	0.18
SD	2.40	0.63	1.55	2.49	0.36	0.63	1.62	0.30	0.40

Note. [a]Ant = Anticipation; [b]Exch = Exchange; [c]Persev = Perseveration

Appendix L, tables 1 and 2, summarize arcsine transformed data for each of the serial order error proportions (number of occurrences of each error type relative to the number of opportunities) for each error type at each speaking rate for NBD participant and PWA, respectively.

10.1.3 Statistical Analyses

The following results were obtained for the primary and secondary experimental questions in this study:

Primary Question One: Is there a significant decrease in the ratio of anticipation to perseveration errors across the three self-manipulated increasing speaking rates, for the NBD participants and the PWA; and is there a significant interaction between speaking rate (normal, fast, faster) and participant group (NBD, PWA)?

Results from a two-way repeated measures ANOVA revealed a significant main effect of rate ($F_{2,46,} = 4.773$, $p = .01$, $\eta^2 = .17$) and a non-significant main effect of group ($F_{1,23,} = .512$, $p = .48$, $\eta^2 = .02$) (power = .11) and no significant interaction ($F_{2,46,} = 1.477$, $p =.24$, $\eta^2 = .06$) (power = .30). With a Bonferroni adjustment for multiple comparisons, there was a significant increase in the AP ratio between the typical and faster rates, but no significant differences between typical and fast or fast and faster rates for both participant groups. See Table 9 for the averaged AP arcsine transformed ratios for both participant groups. Figure 3 illustrates the performance of both groups on the AP error ratio. Visual inspection of Figure 3 reveals a different pattern of performance between the groups, with the NBD group demonstrating an increase in the AP at the faster rate compared to the fast rate, and the PWA demonstrating a very slight decrease in the AP ratio at the faster rate compared to the fast rate. Significant group differences, however, were not obtained. The general pattern of performance for each group is consistent with that for the AE ratio (Figure 4).

Table 9: Averaged arcsine transformed anticipation to perseveration error ratios for the non-brain damaged participants and the persons with aphasia at each speaking rate

Participants	NBD			PWA		
	Typical	Fast	Faster	Typical	Fast	Faster
1	0.852	1.114	0.837	c	1.740	c
2	0.806	1.071	1.164	0.612	1.332	0.625
3	0.972	b	1.537	0.799	0.886	
4	1.373	1.048	2.076	0.738	1.402	2.430
5	0.839	0.739	1.071	2.083	0.833	0.860
6	1.115	1.585	1.797	0.907	0.874	0.941
7	1.099	1.048	c	0.812	0.951	0.977
8	0.899	1.079	1.122	1.025	1.183	1.895
9	0.909	1.081	2.288	1.011	1.681	0.942
10	0.785	1.053	1.387	c	c	c
11	0.970	0.740	1.542	0.739	1.261	0.813
12	0.799	0.905	1.438	1.140	c	c

Table 9 (continued)

13	0.674	1.021	0.923	[c]	0.502	[c]
14	0.857	1.030	1.229	0.860	2.083	0.639
15	1.037	0.781	1.135	1.102	0.986	1.921
16	0.829	0.938	0.959	1.058	1.179	1.394
Mean	0.926	1.016	1.367	0.991	1.207	1.222
SD	0.168	0.203	0.423	0.365	0.421	0.604

Note. [a]AP = Anticipation to perseveration ratio; [b] = Missing data; [c] = No data

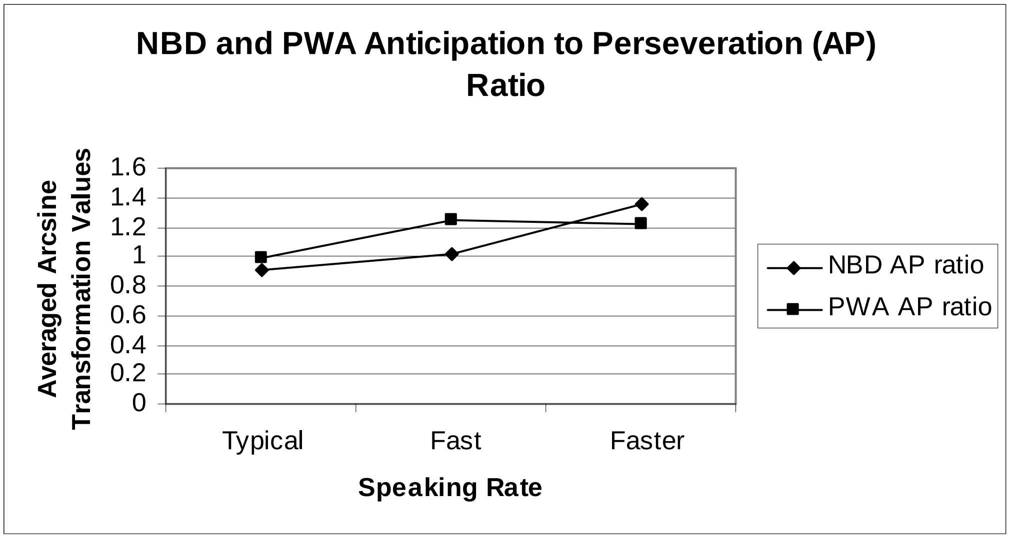

Figure 3: Arcsine transformation values for the anticipation to perseveration error ratio for non-brain damaged participants and persons with aphasia across the three speaking rates

Primary Question Two: Is there a significant decrease in the ratio of anticipation to exchange errors across the three self-manipulated increasing speaking rates, for the NBD participants and the PWA; and is there a significant interaction between speaking rate (normal, fast, faster) and participant group (NBD, PWA)?

Results from a two-way repeated measures ANOVA revealed no significant main effect of rate ($F_{2,46,}$ = 1.727, *p* = .19, η^2 = .07) (power = .34) or group ($F_{1,23,}$ = .907, *p* = .35, η^2 = .04) (power = .10) on the ratio of AE errors. Table 10 presents the averaged arcsine transformed anticipation to exchange serial order error ratios for the NBD participants and the PWA. Figure 4 graphically presents the performance of both participant groups across speaking rates with the arcsine transformed data. Visual inspection of this figure reveals a similar pattern in performance between groups with a nonsignificant but rising ratio of anticipation to exchange errors at increasing speaking rates. This rising trend is in the opposite direction of that predicted. For the AE error ratio measure the observed power was .34 with a partial eta squared of .07. Given the power and effect size of the AE error ratio, a post-hoc power analysis estimated that 56 participants would be necessary in each group to attain a power of .8. The alpha level for all tests was .05.

Table 10: Averaged arcsine transformed anticipation to exchange serial order error ratios for the non-brain damaged participants and the persons with aphasia at each speaking rate

Participants	NBD			PWA		
	Typical	Fast	Faster	Typical	Fast	Faster
1	0.955	1.075	0.692	[a]	1.593	[a]
2	0.782	0.831	0.980	0.662	1.407	0.732
3	0.881	[a]	1.235	1.070	0.571	[a]
4	1.322	1.159	1.860	0.704	1.219	2.553
5	0.953	0.692	0.723	1.679	0.935	0.693
6	1.108	1.414	1.400	1.193	1.006	0.753
7	1.079	1.066	[a]	1.198	0.800	1.177
8	0.879	1.135	0.738	1.512	1.106	1.537
9	0.652	1.287	1.131	1.008	1.890	0.783
10	0.999	1.101	1.614	[a]	[a]	[a]
11	0.940	0.962	1.269	0.667	1.204	0.618

Table 10 (continued)

12	0.855	1.194	1.629	1.124	[a]	[a]
13	0.643	1.056	0.757	[a]	0.660	[a]
14	0.812	0.933	1.114	0.285	1.679	0.671
15	1.071	0.766	0.989	1.032	0.794	1.613
16	0.774	0.999	0.876	1.000	1.193	1.144
Mean	0.919	1.045	1.134	1.010	1.147	1.116
SD	0.175	0.191	0.366	0.370	0.392	0.592

Note. [a] = Missing data

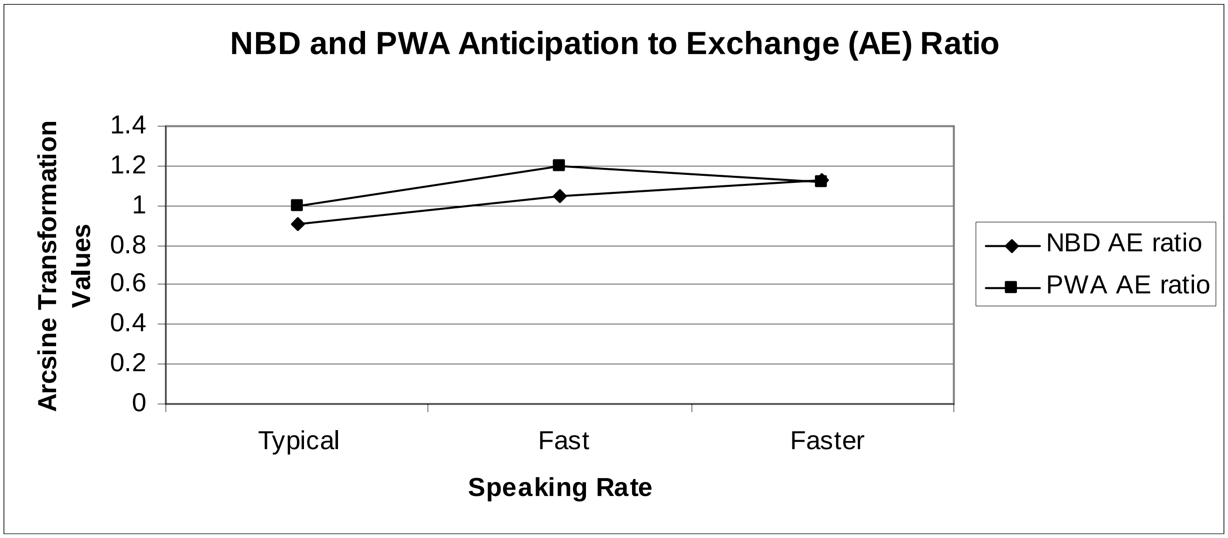

Figure 4: Average arcsine transformed values for the anticipation to exchange error ratio for non-brain damaged (NBD) participants and persons with aphasia (PWA) across the three speaking rates

Secondary Question One: Is there a significant difference in the total number of sound errors (serial order, substitutions, additions, deletions, distortions) produced by NBD participants and PWA among the three self-manipulated speaking rates (normal, fast, faster) and is there a significant interaction between speaking rate and participant group?

The data were analyzed relative to the number of utterances available at each speaking rate for each participant after sentences were deleted from the data pool for not meeting criteria for inclusion. Results from a two-way repeated measures ANOVA revealed no significant main effect of rate ($F_{2,58,}$ = 1.7, p = .19, η^2 = .06) (power = .34) or group ($F_{1,29}$ = .02, p = .90, η^2 = .00) (power = .05) and there was no significant interaction ($F_{2,58,}$ = 2.22, p = .12, η^2 = .07) (power = .44). The results should be interpreted cautiously and there was low power for all tests. See Appendix M, Table M1 for the total number of sound errors for each participant at each speaking rate. See Appendix M, Table M2 for the percentage of sound errors per utterance for each participant at each speaking rate.

Secondary Question Two: Is there a significant difference in the percentage of distortion errors among the three self-manipulated speaking rates (normal, fast, and faster) for NBD participants and PWA and is there an interaction between percentage of distortion errors and participant group?

Results from a 2-way RPM ANOVA revealed a non-significant main effect of rate ($F_{2,58} = .217$, $p = .81$, $\eta^2 = .01$) (power = .08) and group ($F_{1,29} = .974$, $p = .33$, $\eta^2 = .03$) (power = .16), and a non-significant interaction ($F_{2,58} = .037$, $p = .96$, $\eta^2 = .00$) (power = .06). See Table 11 for the percentage of distortion errors for both participant groups.

Table 11: The percentage of distortion errors for each non-brain damaged participant and each person with aphasia at each speaking rate

Participants	[a]NBD			[b]PWA		
	Typical	Fast	Faster	Typical	Fast	Faster
1	0.004	0.012	0.000	0.000	0.000	0.000
2	0.000	0.005	0.007	0.011	0.008	0.014
3	0.000	[c]	0.000	0.000	0.000	0.000
4	0.009	0.009	0.000	0.000	0.016	0.000
5	0.000	0.000	0.000	0.042	0.000	0.000
6	0.035	0.028	0.043	0.003	0.018	0.022
7	0.000	0.008	0.014	0.006	0.000	0.000
8	0.039	0.016	0.008	0.005	0.000	0.000
9	0.018	0.000	0.000	0.000	0.000	0.000
10	0.007	0.004	0.000	0.000	0.000	0.000
11	0.015	0.014	0.028	0.020	0.000	0.000
12	0.006	0.019	0.017	0.009	0.043	0.000

Table 11 (continued)

13	0.018	0.003	0.000	0.000	0.000	0.000
14	0.008	0.000	0.011	0.000	0.000	0.048
15	0.000	0.005	0.000	0.000	0.000	0.013
16	0.000	0.007	0.000	0.017	0.008	0.006
Mean	0.010	0.009	0.008	0.007	0.006	0.006
SD	0.012	0.008	0.012	0.011	0.012	0.013

Note. [a]NBD = non-brain damaged; [b]PWA = person(s) with aphasia; [c] = Missing data

Secondary Question Three: Is there a significant difference in vocal reaction time among the three self-manipulated speaking rates (normal, fast, and faster) for NBD participants and PWA and is there an interaction between speaking rate and participant group?

Results for a two-way repeated measures ANOVA revealed a significant main effect of rate ($F_{2,44,}$ = 13.80 , p = .00 , η^2 = .39) (power = 1.0) and group ($F_{1,22,}$ = 10.15, p = .00, η^2 = .32) (power = .86), and no significant interaction ($F_{2,44)}$ = .99, p = .38, η^2 = .04) (power = .21). Post-hoc pairwise comparisons revealed that the VRTs at each rate were significantly reduced from the other rates. Overall, longer VRTs were produced at the typical speaking rate (M = .604 ms.) compared with the fast (.504 ms); which were significantly longer compared to the faster (.447 ms.) speaking rates. The significant group difference resulted from an overall longer VRT for the PWA (M = .606 ms.) than the NBD participants (M = .432 ms.) at each rate. See table 12 for the average VRT for both participant groups at each speaking rate.

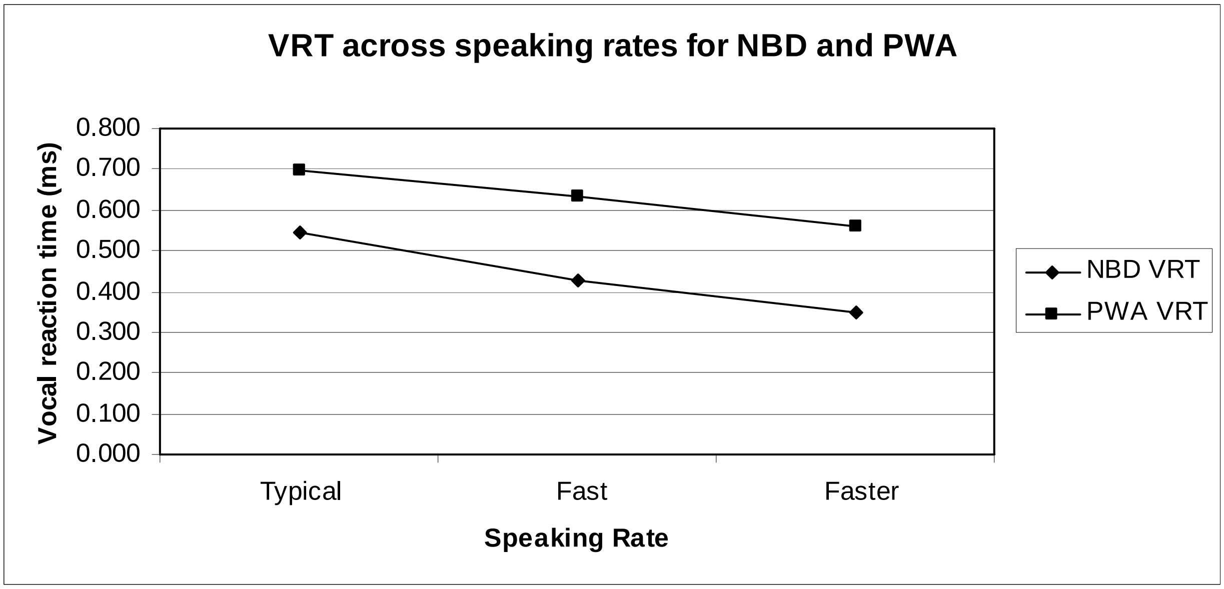

Figure 5: Vocal reaction time (VRT) for non-brain damaged (NBD) participants and persons with aphasia, across each of the speaking rates

Table 12: Average vocal reaction time (VRT) in ms for each non-brain damaged participant and each person with aphasia at each speaking rate

	[a]NBD			[b]PWA		
	Typical	Fast	Faster	Typical	Fast	Faster
1	0.356	0.442	0.327	[c]	[c]	[c]
2	0.719	0.656	0.598	0.808	0.638	0.719
3	0.479	[c]	0.467	1.01	1.095	[c]
4	0.388	0.307	0.27	0.621	0.587	0.365
5	0.466	0.545	0.261	0.366	0.504	0.276
6	0.99	0.531	0.446	0.523	0.504	0.351
7	0.708	0.577	[c]	0.876	[c]	0.597
8	0.429	0.364	0.242	0.635	0.701	0.527
9	0.591	0.364	0.319	0.935	0.514	0.594
10	0.651	0.478	0.404	[c]	[c]	[c]
11	0.377	0.282	0.264	0.699	0.567	0.894
12	0.696	0.439	0.31	0.481	[c]	[c]

Table 12 (continued)

13	0.444	0.335	0.232	[c]	0.548	[c]
14	0.288	0.194	0.203	0.471	0.508	0.627
15	0.664	0.601	0.612	0.912	0.664	0.65
16	0.482	0.324	0.266	0.723	0.742	0.548
Mean	0.546	0.429	0.348	0.697	0.631	0.559
SD	0.182	0.134	0.130	0.203	0.167	0.178

Note. [a]ND = non-brain damaged; [b]PWA = persons(s) with aphasia; [c] = Missing data

11.0 DISCUSSION

This study examined the effects of speaking rate on sound-level serial order speech production errors in NBD participants and PWA. Two predominant speech production models (Dell, 1986; Dell, et al., 1997; Levelt, 1989) acknowledge the influence of speaking rate on phonological encoding. The predictions tested in this study were based on the assumptions and predictions of the interactive spreading activation models of Dell (1986) and Dell, et al. (1997).

In this study, speaking rate was manipulated using an externally cued, but internally regulated direct magnitude procedure such that speaking rate changes were generated relative to each individual speaker's typical rate. Changes in speaking rate were presumed to affect the amount of time available for spreading activation to occur during phonological encoding; having direct consequences for serial order sound-level (i.e., anticipations, exchanges, perseverations) errors. AP and AE error ratios were examined for significant decreases in their proportions relative to speaking rate. Serial order error ratios were formed to measure the change in their relative proportions under varying speech rates. The total number of sound errors was examined to reflect the validity of the speaking rate measure, as an increase in speaking rate should produce more errors (Dell, 1986); particularly for PWA (Dell, Svec, & Burger, 1997). VRT was measured to evaluate whether the task demands of providing an immediate response were met, and to assess whether performance differences existed among groups and/or speaking rates. Both broad and narrow phonetic transcription (for perceptually determined errors) was used to transcribe speech production so that distortion errors could be identified and removed from analysis. These errors were considered to be influenced by motor-level production mechanisms and as such, were not in whole or part attributable to errors at the phonological encoding stage of speech production.

For the primary experimental questions it was predicted that there would be a significant decrease in the relative proportion of both AP and AE serial order errors (proportionally increased exchange and perseveration errors relative to anticipation errors) across the three speaking rates for both participant groups, with the PWA producing a significantly smaller ratio (relatively more exchange and perseveration errors) as speaking rate increased relative to the NBD participants. It also was predicted that there would be a significant interaction between speaking rate (normal, fast, faster) and participant group (NBD, PWA). Primary question one addressed the effect of speaking rate on the AP error ratio. A significant rate effect was obtained for the AP error ratio from the typical to faster speaking rate condition, however, the finding was in the opposite direction of the model's (Dell, et al., 1997) prediction. That is, there was an increase in the AP ratio with increasing (faster) speaking rate, indicating an increase in the number of anticipatory errors relative to perseveratory errors. Only 2 NBD participants at the typical and 2 at the fast speaking rates produce more perseveration than anticipation errors. For the PWA, one participant at each the typical and fast speaking rates, produced more perseveration than anticipation errors. Though not related to a speaking rate task, Wilshire and McCarthy (1996) also reported significantly more anticipations relative to perseverations in a single PWA on several speech production tasks. Similarly, Blumstein (1973) reported more anticipation than perseveration errors in her sample of PWA. These results stand in contrast to those previously reviewed (i.e., Schwartz, et al., 1994) in which PWA with jargon aphasia produced more perseverations than anticipations. As in the current study, Wilshire and McCarthy reported no significant differences in AP between their PWA and the NBD participants.

Dell, et al. (1997) and Martin and Dell (2004) stated that anticipation errors result from the co-occurrence of disrupted activation to the current target and to an upcoming unit in the plan. For an anticipation error to occur, an upcoming sound needs to be more highly activated than the current target. One hypothesis regarding the increase in anticipation rather than perseveration errors with increased speaking rate in this study is that the construction of the phonologically challenging sentences promoted an imbalance between the turn-on and prime functions described in Dell, et al. (1997). That is, elements "in the future' receive activation from the plan, but are also primed with anticipatory activation. The phonemic similarity among phonemes and manipulation of repeated phonemes that make these stimuli phonologically challenging may further prime future elements, and as these elements are all similar, their activation levels may be higher than that of the intended target. It is possible that the increase in speaking rate was not sufficient in magnitude to allow for the effects of a slow decay rate. According to the model, "slow decay favors exchanges and perseverations at the expense of anticipations" (Dell, 1986, p. 300). If in the current study, increased speaking rates were insufficient, the activation level of the anticipated sound would have had time to decay and rebound so that it could be re-selected in its proper location. Support for the possibility of an insufficient change in the rate increase would be provided by the lack of a significant rate effect for the total number of sound errors produced in this study. However, the fact that a change in the proportion of AP errors occurred, though not in the predicted direction, seems to argue against this perspective. Furthermore, if the nature of the stimuli promoted the error findings, similar findings might have been expected to occur in other studies using tongue twister methods. This is not the case, as Dell, et al. (1997), Schwartz et al. (1994), and Vousden and Maylor (2006) all used similar methods producing results different from those of this study. Alternatively, it could be that the specific phonetic contexts or CV structures in the current study biased performance toward increased anticipation errors. Additional research should address this possibility.

Factors related to the methods used in this study may also have contributed to the different findings relative to the predictions. Most previous AP error ratio findings were obtained from normal young to middle aged speakers engaging in a reading or simultaneous reading and listening task. Participant groups in previous studies have not included groups of PWA nor elderly participants. While Vousden and Maylor (2006) included elderly participants, an AP was not able to be established on the older participants as they were not able to meet the task demands of increasing their speaking rates to the metronome.

Primary question two assessed the effect of speaking rate on the AE serial order error ratio. Analysis of the AE ratio revealed no significant main effect or interaction. Neither the manipulation of speaking rate nor the presence or absence of aphasia affected the ratio of AE errors. As the outcome of this analysis was dependent on the behavior of two types of errors an examination of the raw data for both groups is essential in order to interpret the results. The data reveal that few exchange errors were produced in total across all speaking rate conditions. A count of the total number of exchange errors produced in this experiment across all three speaking rates yielded a total of seven exchange errors for PWA and twenty-three for the NBD group. For the PWA, exchanges represented 9%, 6%, and 6% of the serial order errors at the typical, fast and faster speaking rates, respectively. For NBD participants, exchanges composed

16%, 9%, and 15% of the data at the typical, fast, and faster rates, respectively. Thus, even in presumed error producing conditions (increased speaking rate and aphasia) the frequency of occurrence of exchange errors was low. In each participant groups, only 3 of the 16 participants produced more exchange than anticipation errors at any speaking rate. In each of the participant groups, two participants produced more exchanges than anticipations at the typical speaking rate and one participant produced more at the faster speaking rate. The occurrence of few exchange errors is in agreement with previous studies. In the errors collected by Vousden, et al. (2000), 10.6% of the errors were exchanges compared to an occurrence of 35.1% for anticipations and 26% for perseveration errors. Relative to error frequency, the current results also are not unlike those of Dell (1986) in which simulated data from word pairs produced exchange errors in only 5% of the data at the fastest speaking rate, and 3% and 0% at sequentially decreasing speaking rates. In Dell's (1986) human participants experiment, 13% of the errors were exchanges, compared with 80% incomplete exchanges and approximately 4% each of anticipation and perseveration errors at the slowest rate condition. For the fast rate, 29% of the errors were exchanges, 56% incomplete exchanges and 10% and 4% for anticipation and perseveration errors respectively. Finally, at the fastest rate, exchanges made up 35% of the errors, incomplete exchanges 55% of the errors and anticipation and perseveration provided just 8% and 2% of the errors, respectively. The high number of exchange errors was due to the experimental procedure used to induce the sound errors. While initially, significant differences were obtained for exchange errors, once incomplete exchanges (errors that may only be anticipation errors as the initial error is self-corrected, or production is stopped before the second word of the pair is produced) were removed from that data, no effects were found.

The only evidence from human participants supporting the model's prediction comes from an unpublished study by Fossett, et al. (2000). In that study word pair and sentence stimuli were used to elicit production errors. A significant increase in the number of exchange errors was found when comparing the typical and fast and typical and faster speaking rates for the sentence stimuli, however no significant differences were observed between the fast and faster speaking rates for the word-pairs. Results for sentence stimuli revealed significant increases in the number of exchange errors from the typical to faster and fast to faster speaking rates, but not between the typical and fast speaking rates. No significant differences in the number of anticipation errors was produced among speaking rates for word-pair stimuli, however, a significant increase was obtained for sentence stimuli between the typical and fast and typical and faster rates, but not between the fast and faster speaking rates. The current study used the same sentence stimuli and rate manipulation procedures as the Fossett, et al. (2000) study, however, word-pairs were not used in the current study. Differences in data analysis procedures likely contributed to the difference between the findings of these two studies.

A primary difference in data analysis was the categorization of tokens relative to speaking rate. In the Fossett, et al. (2000) study, utterances produced at a specified rate were categorized at that rate provided the total duration fell within the mean and 1 SD. In the current study, however, it was not assumed that an utterance produced at the instructed rate was actually realized at that rate. Therefore, in order to include as many legitimate tokens as possible for analyses, and to accurately reflect the specified rate variation, tokens in this study were re-categorized based on the rate at which each token was actually produced. This strategy of re-categorization may have contributed to different findings between the studies.

Next, in the Fossett, et al. (2000) study, data analyses were computed separately on the *number* of errors produced for each error type separately. Additionally, error proportions were not directly compared, but rather each was compared with the total number of sound errors produced. In the current study statistical analyses were computed only on the number of errors relative to the numbers of opportunities for that error to occur; and then on *proportions* of error types after being distribution normalized. The transform was used to eliminate zero entries in the calculation that directly compared error proportions (i.e., AE, AP) and to distribute them for inferential statistical analyses. Thus, results for this study are based on the direct comparison of each error type proportion and not on each serial order error type relative to the total number of errors produced.

The exchange to anticipation ratio error data cannot be compared directly with the experimental data obtained from the NBD young adults assessed by Dell (1986). Not only are the participant age groups substantively different between studies, the data in the Dell study were obtained using word pairs which biased error generation towards the production of sound exchange errors. Stimuli in the current experiment were phonologically challenging sentences, and while constructed to induce sound errors, were not designed to bias production towards any specific serial order error type. Analyses in the current study also differ from those in Dell (1986). That is, analyses in the Dell study addressed the relative proportions of exchange and anticipation errors relative to the number of errors produced. However, if the data from the current study for the NBD participants had been analyzed relative to *number* of errors, results for sound exchange errors would also have yielded no significant effects of rate $\chi^2(2, N = 10) = 4.39$, $p = .11$). Thus, even based on actual counts of exchange and anticipation errors, the AE error ratio calculated as AE would have yielded results different from those predicted by the Dell

(1986) model, at least for the NBD participants. This demonstrates that the differences in analyses did not account for this null finding. Thus, these results, regardless of the analysis procedure, do not support the prediction of an increase in the number of exchange errors with faster speaking rates.

A methodological variable concerning the appropriateness of the analysis used in Dell (1986) and for some data from Fossett, et al. (2000), concerns the nature of the stimuli. In both of these studies stimuli consisted of CVC word-pairs constructed to induce serial order errors on the initial consonants of the cued target word pairs. Serial order errors could only occur in the initial position of these words pairs given phonotactic and structural constraints. As such, these stimuli limited the opportunity for serial order errors to occur. This was not the case for the phonologically challenging sentence stimuli in Fossett, et al. (2000) or the stimuli used in more recent investigations by Dell, et al. (1997), Schwartz, et al. (1994), and Vousden and Maylor (2006). The sentence stimuli in the current study were composed of single and bi-syllabic words of various CVC constructions and were designed so that serial order errors could potentially occur in a number of different sentence positions, but not with equal probability. The rationale for using sentence stimuli as opposed to CVC word stimuli was to increase the potential number of analyzable serial order sound errors. So, despite the challenges inherent with errors produced in sentence stimuli, and the resulting null findings, it is argued that the current data analysis provides a more accurate method of analysis of the data for a direct assessment of the model.

The effect of speaking rate on the presence of serial order exchange errors has not been adequately tested. As previously noted, the finding of a significant difference in the exchange to anticipation ratio across speaking rates in Dell (1986) was eliminated once incomplete exchange errors were removed from the analysis. That finding reduced the available support for the prediction and yielded findings similar to those obtained in the current study despite differences in methods. It must be remembered, however, that results from the current study do not provide support or counter evidence for the AE ratio prediction because of the low power for the statistical tests. From a theoretical perspective, based on the sheer paucity of relevant errors, this lack of evidence may raise questions about the influence of temporal processing and the behavior of spreading activation relative to the frequency and conditions under which exchange errors occur. According to Dell (1986), exchange errors are not independent of the occurrence of anticipation or perseveration errors. He asserts that the production of an exchange error is related to the integrity of all processing functions and is affected by the degree of anticipatory or perseveratory bias present during processing. Given the limited frequency of occurrence of serial order sound exchange errors in two human experimental studies, it may be that they are theoretically less interesting than other serial order error types. Although the lack of statistical power observed in this study limits interpretation, the extreme paucity of exchange errors at any speaking rate does dampen their theoretical utility. Likewise, their clinical significance and utility as a differentially diagnostic sign is substantively diminished by these findings.

Activation decay rate (Dell, 1986) and connection weight strength (Dell, Burger, et al., 1997; Martin & Dell, 2004) have been postulated as parameters that may affect the occurrence of different types of serial order speech production errors. While according to the model (Dell, 1986), spreading and decay rates remain constant regardless of speaking rate, Dell proposed that slow decay rates were more likely to result in exchanges and perseverations rather than anticipations. The suggestion is that while at slow speaking rates activation from previously selected items would likely still have time to decay, at faster speaking rates, activation from those items may remain relatively high as not enough time may have elapsed to allow for activation decay. This maintained high activation level might allow an item to be re-selected, leading to more perseveration errors at faster speaking rates. Dell and colleagues (1997) acknowledge a suggestion from Stemberger (1989) that children, who have been demonstrated to have higher APs than adults, may have a slower rate of activation decay than adults. This suggestion counters the perspective of Dell and colleagues, who hypothesize that the lower AP findings in children are due to decreased connection strength. An alternative to the proposal of slow decay, however, is the consideration of fast decay. If the rate of activation decay is generally more rapid, the tendency for an increase in perseveration or exchange errors might not be observable unless speaking rates were exceedingly rapid. The alternative possibility of fast decay has been suggested by others (Martin, et al., 1994) and is acknowledged by Dell and colleagues (1997), relative to the potential effects of brain damage on AP. However, the alternative explanation of fast decay as presented here is not specific to the effects of brain damage, as in the current study no group differences were obtained for the serial order and speaking rate questions.

Yet another variable to consider relative to the rate of activation decay concerns the time necessary for residual activation to re-bound to a high enough level for an item to be re-selected. At fast speaking rates, time may be too limited to allow sufficient re-bound for items to be re-selected. This would result in the production of more anticipation errors because of the timing of activation levels at the rapid speech rate, with the consequences of few perseveration errors (and exchange errors) because activation levels would not re-bound quickly enough to allow items to be re-selected. Thus, while Dell (1986) proposed that slow rates of activation decay would allow for higher numbers of perseveration errors, fast activation decay and/or slow re-bound of activation following activation decay are plausible alternative suggestions that would accommodate the results obtained in this study.

Martin & Dell (2004) stated that reduced connection strengths result in lower activation levels of target items and thus residual activation may more easily achieve high enough levels to allow previously selected items to be available for re-selection. They further stated that brain damage is usually associated with weak connections. Using a spreading activation model similar to that of Dell (1986), Martin, et al. (1994) also suggested decreased connection strength, related to brain damage explained production differences between a PWA and simulations of the production performance of NBD participants. However, decreased connection strength would not explain the current findings as no group differences were obtained on the serial order speaking rate questions and there is no reason to posit decreased connection strength in the NBD participant group.

Secondary question one assessed the effect of speaking rate on the total number of sound errors. It was predicted that there would be a significant increase in the total number of sound errors produced across the three speaking rates between groups and that there would be a significant interaction with the PWA producing significantly more errors than the NBD participants at all rates. The lack of a significant main effect or interaction for this analysis was unexpected, although the finding should be viewed with caution due to the low statistical power. Indeed, several previous investigations of serial order sound errors have revealed a significant increase in total errors at faster speaking rates (Dell, 1986; Dell, et al., 1997; Wilshire , McCarthy, 1996; Vousden & Maylor, 2006). Fossett, et al. (2000), however, reported no significant difference for total errors across speaking rates for word pair stimuli in NBD participants, but they did report a significant finding for the sentence stimuli; those same stimuli used in the current study. One explanation for the lack of a speech rate effect in this study may be related to the way stimuli were re-organized and categorized in this study to form the different speaking rate data. As previously described, in the current study, a token produced in the instructed "fast" rate condition, may have been actually produced at the participant's typical speaking rate. For the analysis, that token would have been analyzed as a "typical" speaking rate token. In the Fossett, et al. (2000) study, no such re-categorization of produced utterances occurred. A token determined to have not met the established criteria at that instructed speaking rate was eliminated from further analysis. The determination to re-categorize responses in the current study was based on the decision that the rate at which the token was actually produced was most relevant for assessing the effects of speaking rate on the production of serial order errors.

As indicated above, another possibility for the lack of significant differences in the total number of sound errors produced is that the magnitude of rate change increase was not sufficient. Consideration of this possibility suggests exploration of procedures used to manipulate speaking rate. In most of the previously mentioned studies (Dell, et al., 1997; Schwartz, et al., 1994; Vousden & Maylor, 2006) investigating the effects of speaking rate on phonological serial order errors, rate manipulation was accomplished by requiring speakers to match their rate to a metronome (see Dell (1986) and Dell (1990) for a different rate manipulation procedure). Unfortunately, studies in which a metronome has been used to change speaking rate have not confirmed that participants consistently performed at the targeted rate. While this does not appear to explain the consistent and predicted findings in the previous studies, it is possible that experimental error in the categorization of the errors by speech rate could account for this disparity. Even if the metronome produces a specified rate change, it may place different processing demands on some individuals as typical speaking rate varies from person to person. Additionally, some participants may have difficulty matching their rate to that of the metronome and thus be unable to do the task (Vousden & Maylor, 2006) or they may accomplish the rate change using varied production strategies that could affect the proportion of serial order errors. This may have particular relevance for the present study because of the age of the participants and the inclusion of PWA. As previously mentioned, while it has been demonstrated that PWA are able to change their speaking rate (Baum, 1996; McNeil, Liss, et al., 1990), they do so less consistently and within a more restricted range than do NBD speakers. Furthermore, Tsao, et al. (2006) suggested that speakers produce greater changes in speaking rate at the slower than faster rates.

An alternative hypothesis to explain the lack of a significant rate or group effect on the total number of sound errors produced is that a significant difference might have resulted if word/non-word errors had been included in the analysis, because lexical errors are common, particularly in the speech production of PWA (Dell, Schwartz, et al., 1997). The presence of these errors substantively reduces the error types of interest for this analysis. As described in the Dell (1986) model, speaking rate manipulation is assumed to affect all levels of language processing (e.g., lexical bias, semantic bias). Thus, it is possible that had more tokens met the inclusion criteria and if word/non-word errors had been included in the analysis a significant difference in the total number of sound errors might have been demonstrated.

The second secondary question assessed the effects of speaking rate on percentage of distortion errors produced. It was predicted that there would be significant differences in the percentage of distortion errors produced across the increased speaking rates for both groups, with no significant interaction. The lack of significant differences between participant groups suggests that, as indicated by initial screening measures and clinical judgment, the group of PWA were not different from the NBD participants in their speech motor performance as revealed by the presence of sound-level distortions.

Previous research has revealed effects of speaking rate manipulation on various acoustic (e.g., voice onset time, segment duration) measures in NBD and brain-damaged participants (Baum, 1996). This evidence has revealed some performance differences between NBD speakers and PWA with different levels of rate manipulation (Baum, 1996). Thus, for the current study, it was reasonable to expect an effect of rate manipulation and an interaction on the percentage of distortion errors. However, unlike the participants in the current study, these data were obtained on PWA for whom cognitive-linguistic-motoric level processes were not well described or delineated. So, while it was predicted that there would be a significant effect of rate, an interaction was not predicted. Whatever the eventual interpretation for this finding, low statistical power limits the interpretability of these data.

Secondary question number three addressed the effects of speaking rate on the VRT. The primary purpose of this measurement was to provide evidence that participants had met the task demand of responding immediately after the tone cue and no significant effects of rate or group were predicted. The results, however, revealed significant effects of speaking rate and group, but no interaction. As reported, means for the PWA group were longer than those of NBD participants at all speaking rates. These findings replicate those reported in Fossett, et al. (2000) with similar means reported for the NBD participants. While other studies have investigated the effects of speaking rate on phonological encoding (Dell, 1986; Dell, et al., 1997; Vousden & Maylor, 2006; Wilshire & McCarthy, 1996), none have provided evidence that participants responded immediately after the cue to speak. Failure to initiate speech immediately after stimulus presentation could allow additional processing time for phonological encoding and might not validly reflect only the effect of the speaking rate manipulation. The decrease in VRT with the demand of increasing speaking rate is thought to reflect a decrease in preparation time with a concomitant reduced response time as a result of the time pressure to respond. When required to produce speech at a faster overall rate, the task demands appear to have carried through to pre-motoric production levels, as intended. As the same stimuli occurred in all speaking rate conditions in the current study, stimulus variables (i.e., complexity, number of syllables) did not contribute to this result.

As PWA were screened for motor-level deficits, the finding of a group main effect for VRT was surprising. Data from Towne and Crary (1988) suggested that participants with more posterior lesions produced verbal reaction times similar to NBD participants. Their conclusion was based on data provided by two PWA described as posterior-lesioned participants with mild anomia and mild conduction aphasia. The participants in the current study for whom lesion data was available, generally demonstrated posterior lesions, although lesion data was not obtained for all participants. However, it should be noted that PWA frequently demonstrate longer reaction times relative to NBD participants in language tasks (Bose, van Lieshout, & Square, 2007; Dunn, Russell, & Drummond, 1989), regardless of modality. Participants did not demonstrate motor speech deficits on the screening measures and therefore the increased level of response planning and execution appears to be related to phonological encoding processes in the PWA compared to the NBD participants.

12.0 SUMMARY

This study provided some support for the prediction that speaking rate can affect phonological encoding as reflected in changes in the proportions of serial order sound-level errors. While results for one (AP) of two serial order ratios was significantly affected by speech rate, the finding was in the opposite direction (a rise in AP ratio) of that predicted by the model of Dell (1986) and Dell, et al. (1997). The finding was also not supportive of an alternative theoretical perspective (McNeil & Kent, 1990) which suggested that speaking rate manipulation should be affected by deficits at the motor level of speech production and not phonological encoding. Additionally, no significant main effect of group and no significant interactions were obtained. Previous research has produced inconsistent results of speaking rate on various serial order errors in NBD persons (Dell, 1986; Dell, et al., 1997; Fossett, et al., 2000). However, no previous studies have specifically manipulated speaking rate in a sentential speech production task with a group of PWA. Stringent inclusion and exclusion criteria for participants and response inclusion substantively limited the amount of analyzable data that was available and the number of participants from whom it was collected. Data were obtained from NBD participants, as well as, PWA, who demonstrated no clinical evidence of a motor speech deficit. These stringent inclusion and exclusion criteria resulted in an analysis of sound errors that can more confidently be attributed to the level of phonological encoding as posited by several speech production models (e.g., Dell, 1986; Levelt, 1989, Van der Merwe, 1997). Additionally, use of narrow phonetic transcription provided added assurance that those identified serial order errors were correctly attributed to disruption at the level of phonologic encoding (McNeil, et al, 1997). The importance of this is that these data are not subject to the criticism posed by McNeil, et al., (1997) of the majority of existing data from PWA that they include errors that could not be assigned confidently to the phonological level or to the phonological level only.

Differences in methods in the current study as compared to previous studies may have contributed to the serial order findings that do not provide supporting evidence for the model of Dell (1986) and Dell, et al., (1997). The primary method that is different among studies is the procedure used to manipulate speaking rate. The current study used a direct magnitude production procedure to change speaking rate. This procedure allowed rate manipulation to be controlled relative to the individual participant's production system. This allowed the induction of different amounts of change depending on the participant's typical speaking rate and did not constrain all speakers to uniform rates, even though those rates might have represented very different portions of their individual operating ranges. That is, the uniform rate method for eliciting changes in previous studies may have produced rates that represent different portions of the individual's operating ranges, which could create different rate generating strategies among individuals. Use of a metronome to determine speech rate used in the other studies, may have imposed an artificial rate change that may not reflect the same amount of rate change for each participant. Thus processing time constraints, as controlled by the metronome speaking rate manipulation, may not be similar for all participants and might lead to false conclusions about performance. There is also the high probability that speech synchronized to a metronome has a primary impact on the timing of various events within phonological encoding and hence, could have contributed to the effects observed in the previous studies that have used it. Other studies

(Dell, 1986, 1990) imposed a deadline signaled by a tone to manipulate speaking rate. While different from the metronome, the procedure used in Dell (1986) and Dell (1990) also imposed a specified time limit on production that may have placed different demands on participants depending on their individual typical speaking rates. Evidence supporting the use of the method used in the current study was provided by the significant effect of rate obtained with one of the serial order error ratios investigated in this study.

Another difference in the methods used in the current study as opposed to previous studies is the measurement of VRT. In studies investigating the effect of speaking rate on phonological encoding the task demand (implied or stated) is that participants respond immediately. It is important that participants respond immediately so that productions reflect as much as possible, only the results of phonological encoding to the point at which a response was required and so that the potential for editing of that processing is minimized or eliminated. However, most previous studies have not demonstrated evidence that this task demand has been met. VRT data in the current study were obtained only on target stimuli and not compared with filler items as these items were not produced. However, VRT data in this study for the NBD participants were similar in duration and differences between speaking rate to those reported in Fossett, et al. (2000). Though there were differences with the current study in data organization, VRT data in Fossett, et al. (2000) study were subject to statistical analyses and similar findings for speaking rate were yielded. These data provide some concurrent validity for the VRT findings in the current study, especially as both studies used the same stimuli for production and methods for rate manipulation. The task demands of varying speaking rate may affect the total duration of the produced utterance as well as the preparation time for producing the utterance, as reflected in both the Fossett, et al. (2000) and current study data. It is important that the results of these two different measures (VRT and total duration) be disambiguated, to provide evidence that the tasks demands of immediate responding and speaking rate manipulation have been met. Changes in total utterance duration reflect changes in speaking rate while changes in VRT reflect response preparation or planning processes.

Though the current study used methods that have been interpreted to be advantages relative to other studies, null results were obtained for many of the experimental questions. It is important to acknowledge that the low power for most statistical tests make the null findings in this study uninterpretable. Nonetheless, the significant findings which were demonstrated provided data that address issues relating to the relationship of serial order phonological errors to increased speaking rate. It is speculated that the methods introduced in this study (narrow phonetic transcription, direct magnitude production procedure, immediate responding using direct acoustic measurement of vocal reaction time) may provide a more valid assessment of these relationships.

The results of this study may have implications for the speaking rate assumptions of Dell (1986) and Dell, et al. (1997). The finding of an increase in the proportion of anticipation as opposed to perseveration errors in this study challenges the assumption regarding the effect of speaking rate on the proportions of serial order errors. Specifically, relative to the model, this finding suggests that the priming function which is conceived of as necessary to have access to the present and future parts of an utterance, may be more sensitive to change in speaking rate than the turn-off or inhibition function. The current findings argue for an alternative concept of the role of activation and decay in influencing types of serial order sound errors. Based on the assumptions of the Dell (1986) model, a slow activation decay rate was compatible with the stated speaking rate predictions. The results of the current study are more compatible, however, with the alternative explanation of rapid activation decay or slow build-up of residual activation. Thus the findings of this study provide some evidence that speaking rate change or the available encoding time can affect the proportion of serial order errors produced. The initial proposed rationale for how this is accomplished was not consistent with the results of this study. However, these findings do provide support that phonological encoding is time dependent and suggest that phonological encoding processes can function independently of motor processes. These findings provide supporting evidence that serial order sound-level errors can be unambiguously assigned to the level of phonological encoding and have value for differential diagnosis from other sound-level production deficits. Some caution is suggested with interpretation of these results as the data were obtained with experimentally manipulated stimuli designed to elicit speech production errors through the manipulation of repeated and similar phonemes, a condition not typically encountered in everyday speech production.

The results of this study, with a main finding different than that predicted, have generated further questions regarding the effect of speaking rate on phonological serial order error ratios. A future study should replicate and extend the current study. This next study should further investigate speaking rate effects on phonological encoding in a group of participants with only a motor-speech deficit and no cognitive-linguistic deficits. Performance similar to NBD participants would be expected and would provide further supporting evidence for the speaking rate predictions that have been examined. It is suggested however, that a future study include many more participants and stimuli than in the current study, in different tasks and with more than one procedure for manipulating speaking rate. Furthermore, it is suggested that as strategies for rate manipulation may differ among individuals (Tsao, et al., 2006), additional measures of rate change should be addressed (i.e., articulation rate, pause time).

12.1 STUDY LIMITATIONS

The following are some limitations of this study:

(a) Generalizability – As indicated by performance on descriptive and screening measures, participants in this study would be generally clinically characterized as demonstrating mild to moderate aphasia.

(b) Speaking rate change – With the rate manipulation procedure used in this study, it is not possible to obtain precise changes in rate of a specific magnitude within and/or between participants. Additionally, on-line determination that the rate manipulation criterion has been adequately met is not possible at this time.

(c) The population of PWA with no motor speech deficits is limited. This limitation may make replication of this study difficult to obtain.

To further investigate variables of phonologic encoding that might contribute to differential diagnosis for PWA, it is suggested that this research be extended to consider other speech production models that specify processing at the level of phonological encoding (i.e., Roelofs, 1997; Vousden, et al., 2000). These models posit different mechanisms and explore different data from the Dell (1986, 1988) and Dell, et al., (1997) models, however, these models might assist in the examination of the processing differences that exist between NBD speakers and persons with aphasia, especially as related to the effects of speaking rate on serial order phonological encoding processes.

APPENDIX A

INSTRUCTIONS

Practice: Typical Speaking Rate

“You will hear 8 sentences. After each sentence, you will hear a beep. Say each sentence as soon as you hear the beep. Say each sentence as you normally would.”

Practice: Fast Rate

“Now I want you to change how fast you speak. You just said 8 sentences at your typical speaking rate. Now I want you to make your speech faster. Please look at the bar on this page. This bar (examiner runs finger the entire length of the line) represents the entire range of how fast you can speak. This line (examiner points to the line with the arrow above it) shows how fast you just spoke. It shows your typical speaking rate (examiner draws an arrow pointing down above this mark). This line (examiner point to the line immediately to the right, which represents a faster rate) represents you speaking faster than normal. And this line over (examiner points to the line that represents an even faster rate) here, represents you speaking even faster rate. This line (pointing to bar at very end of the line) is the absolute fastest you could ever speak.”

“What I want you to do now is to make your speech *this* fast (examiner points to the next vertical line on the bar). However fast you think this might be, that’s how fast I want you to go.

It’s *not* the *fastest* that you can go, (examiner points to very end of horizontal head and shakes head). And you can still go faster, because there’s another line before you get to the end of the bar. But it *is* faster than your typical speaking rate (examiner points to line representing typical speaking rate). You will hear the sentences one right after the other. If you make mistakes when speaking, don’t go back and try to fix them, just keep going. It is important to begin speaking as soon as you hear the beep. Again, make your speech this fast. Ready?”

Encouragement/verbal and visual cues, “Try to go a little faster,” “Good, that’s just what I want you to do,” or “That’s just right.”

<u>Practice</u>: Faster rate

“Ok, you will hear those sentences again. Now make your speech even faster. Make your speech *this* fast (examiner points to the next vertical line on the bar). However fast you think this might be, that’s how fast I want you to go. It’s *not* the *fastest* that you can go (examiner shakes head and points to line at the very end of the bar). But it is faster than your typical speaking rate and the rate at which you just spoke. Say the sentences immediately after the beep. It’s ok if you make mistakes when you are speaking. Don’t go back and try to fix them, just keep going. It is important to begin speaking as soon as you hear the beep. Again, make your speech this fast (examiner points).”

<u>Practice responding after the beep</u>:

“Now you will hear those sentences again. This time there will not be a beep after every sentence. Only say the sentence when you hear a beep. Say the sentence immediately after the beep. Say these sentences at your normal rate, but only when you hear the beep. If you make mistakes when you are speaking, don’t go back and try to fix them, just keep going. Say these sentences at your normal rate (examiner points), but only when you hear the beep." "Now let's move on to the real thing."

Experimental: ***Typical*** Speaking Rate Task

"Now you will hear some sentences. After some of them you will hear a beep. Say each sentence aloud immediately after the beep. Say these sentences at your typical speaking rate" (examiner points to line representing this rate). Say these sentences at the rate, this line (examiner points to line) represents for you (examiner draws arrow above target rate). Only say the sentences when you hear a beep. The sentences will follow one after another. If you make mistakes when speaking, don't go back and try to fix them, just keep going. Remember, only say the sentence when you hear a beep. It is important to begin speaking immediately after the beep. Again, this time, speak at your typical speaking rate (examiner points)."

Encouragement/verbal and visual cues, "Try to go a little faster," "Good, that's just what I want you to do," or "That's just right."

For ***FAST*** speaking rate:

"Now you will hear some sentences. After some of them you will hear a beep. Say each sentence aloud immediately after the beep. Say the sentences at this rate (examiner points to appropriate vertical line). However fast you think this might be, that's how fast I want you to go. It's *not* the *fastest* you can go, (examiner points to very end of horizontal line and shakes head). You can still go faster, because there's another line before you get to the end of the bar. But it *is* faster than your typical speaking rate (examiner points to line representing typical speaking rate). You will hear the sentences one right after the other. If you make mistakes when speaking, don't go back and try to fix them, just keep going. Remember, only say the sentence when you hear a beep. It is important to begin speaking immediately after the beep. Again, make your speech this (examiner points) fast. Ready?”

Encouragement/verbal and visual cues, “Try to go a little faster,” “Good, that’s just what I want you to do,” or “That’s just right.”

For ***Faster*** speaking rate:

“Now you will hear some sentences. After some of them you will hear a beep. Say each sentence aloud immediately after the beep. Say the sentences at this rate (examiner points to appropriate vertical line). However fast you think this might be, that’s how fast I want you to go. It’s not the fastest you can go (examiner points to very end of horizontal line and shakes head). But it is faster than your typical speaking rate. A lot faster. Say these sentences this fast (examiner points to line and draws arrow above target rate). You will hear the sentences one right after the other. If you make mistakes when speaking, don’t go back and try to fix them, just keep going. Remember, only say the sentence when you hear a beep. It is important to begin speaking immediately after the beep. Again, make your speech this (examiner points) fast. Ready?”

Encouragement/verbal and visual cues, “Try to go a little faster,” “Good, that’s just what I want you to do,” or “That’s just right.”

.

APPENDIX B

EXPERIMENTAL TONGUE TWISTER STIMULI

A blinding blizzard blew briefly

The grouchy group groaned gloomily

Frightened Fred fries fresh flour

The flighty fleeing flea flew free

Glenda’s gleaming glove glimmered green

Brad bravely broke Brooke’s brittle blades

The grim grizzly grabbed grimy glue

Frank fried fragrant frozen flounder

The classy clown cleaned clay crabs

Gleeful Glenn glued the glass grape

Flopping Flipper flipped friskily

Brawny Brett’s brilliant bride blinked

FILLER TONGUE TWISTERS STIMULI

Barbara burned the brown bread badly

Nimble Nat never knits knick-knacks

Shy Sherry shakes soft shiny silks

The sharp sort shoot sharks straight through

Saucy Suzie sneezes slightly

Sell shimmering satin sashes

Stella still skips steps skillfully

Perky people pick peppy pets

Tickled Tina’s team took Tim tea

The tired tiger’s tan tail tapped time

The noon needle nicked Ned’s neck

I know novel noises needed notice

The moody moose must move much mud

Sam showed Cindy soft shiny sweets

The winter wind whipped while Will walked

The wet resting whale rolled west

The worn watch will work with winding

Wide white wood with wire was wanted

The sun shines on stop signs shortly

The rig’s rake ripped Ray’s rear roof

The round root rubbed Ruth’s red rug

Messy mail may make men mad

Waking Wendy’s worms were waiting

Tom caught Todd tying kites tightly

APPENDIX C

TRANSCRIPTION RELIABILITY INFORMATION AND RELIABILITY DATA

Inter- and intra-rater reliability was established on a portion of broad and narrow phonetic transcription. Accuracy of production always was determined by the examiner's perceptual judgment. Transcriptions were based on multiple replays (as necessary) of the digitized sound files and were recorded on a data sheet along with the orthographically transcribed sentence.

Transcription Reliability

Inter-rater transcription reliability was established between the examiner and another licensed speech-language pathologist. Intra-rater reliability was also obtained with 80% and 50% agreement used as criteria for acceptable inter- and intra-judge reliability for broad and narrow phonetic transcription, respectively. The raters were given the opportunity to become familiar with the transcription system and to practice transcribing before any attempts to establish intra- or inter-rater reliability on target stimuli. Point-to-point reliability for narrow phonetic transcription represented whether raters agreed that the production contained an error that was best captured by narrow phonetic transcription, to determine if raters identified the same sound as erred and if so, if the same symbol was used to represent the error. Judges were allowed unlimited stimulus replay to yield the greatest accuracy of transcription.

The calculation for establishing reliability was:

$$\frac{\text{Total number of phonemes in agreement}}{\text{Total number of phonemes in agreement + disagreement}}$$

For training, the raters were provided with the Shriberg and Kent (1995) text and were instructed to review the text, and specifically, to become re-familiarized with the narrow phonetic transcription symbols. They were then given nine practice stimuli to transcribe (three sentences at each of three speaking rates produced by NBD participants). Transcriptions from both raters were subsequently reviewed and any transcription differences were discussed and verbally resolved.

To establish initial inter- and intra-rater scoring reliability the raters were given 24 target stimuli, randomly chosen from four NBD participants and 24 randomly chosen from four PWA. Sentences represented 16% of each of the speakers' potential productions with two sentences from each of the three target speaking rates. Target stimuli were used to establish reliability because errors were rare in the practice sentences, as those sentences were not phonologically challenging. Differences in transcriptions were discussed after reliability measures were obtained and the rules further reviewed. Next, the investigator transcribed all possible utterances from each participant in both participant groups. Then, inter-rater reliability was established on a randomly chosen 16% of each of the PWA and NBD participants' productions previously transcribed by the investigator (two sentences at each of the three speaking rates for each participant).

The concept of near functional equivalence was used in determining inter- and intra-rater reliability. Near functional equivalence (Shriberg & Kent, 1995) was counted as an agreement. These judgments included, but were not limited to, /I/ for /ə/ in unstressed syllables (e.g., gloomi̲ly), syllabic /n/ and syllabic /l/ for /ən/ and /əl/ respectively, and /n/ for /ŋ/ when preceding a velar phoneme (e.g., Frank). Inter and intra- rater reliability was calculated on all phonemes produced that were an attempt at the stimulus. Descriptive behaviors (i.e., appropriate aspiration, unreleased final unvoiced plosives) were transcribed, if observed however these behaviors did not contribute to the determination of intra- and inter-judge reliability.

Transcription Reliability Data

Point-to-point inter-rater reliability for phonetic transcription was obtained on each of the 32 participants, while intra-rater reliability was obtained on 25% of the participants for one rater. Point-to-point inter- and intra-rater reliability was established for phoneme error agreement and for narrow phonetic transcription symbol agreement. Reliability results for narrow phonetic transcription are based on fewer tokens because all productions did not warrant narrow phonetic transcription. Inter-rater reliability results for broad phonetic transcription yielded point-to-point agreement of 94% and 88% for the NBD and PWA participant groups, respectively. Narrow phonetic transcription for identification of the need for a diacritic was 55% for both groups. Identification of the phoneme needing a diacritic was high for both the NBD (100%) and PWA (95%) participant groups. Similar inter-rater agreements were achieved for use of the same diacritic symbol with 100% and 91% agreement for NBD participants and PWA, respectively.

APPENDIX D

ERROR CODING GUIDELINES

1. Sound, syllable and word repetitions, self-repairs, and unintelligible words that did not perceptually result in a phonemic anticipation, perseveration or exchange error were not coded for errors as responses containing these behaviors generally failed to meet the above mentioned criteria.
2. Coding categories included the following: anticipation, perseveration, exchange, distorted anticipation, distorted perseveration, distorted exchange, sound distortion (approximation of target sound), sound substitution (replacement of a single phoneme with a sound not contained in the target), distorted sound substitution, sound addition, sound deletion, ambiguous, whole word anticipation, whole word perseveration, whole word exchange, whole word substitution, and non-word (see Appendix for guidelines and definitions of error categories). Importantly, a sound substitution error was characterized as an error in which the produced sound was perceptually identified as an undistorted phoneme other than the target.
3. Error classification for the categories of anticipation, exchange, and perseveration was based on the sound environment closest to the target.

4. A coding category of “ambiguous” was assigned in those cases in which no clear categorization for error type was apparent (i.e., a possible source precedes and follows the error location at the same distance).
5. Whole word addition and omission categories were not included as they indicate a difference in the number of syllables produced relative to the target, a violation that would not allow the produced utterance to be used for data analysis
6. Anticipation and perseveration errors are coded relative to the target.
7. Anticipation, perseveration and exchange errors can occur across syllables (other words in the sentence) that contain one of the two error units.
8. Anticipation and perseveration errors may or may not be in the same structural relationship (i.e., CVC, CCVC) as the target sound.
9. If an error has a potential error source both before and after it, proximity will be used to determine if the error is to be categorized as an anticipation or perseveration error.
10. If an error involves a target sound with potential error sources before and after it and the distance from the error to the two potential error sources is equal, then the error is scored as ambiguous.
11. Distortions are coded if the production is perceptually different from the target at a sub-phonemic level. Erred productions can be distorted (i.e., distorted anticipation).
12. Each single phoneme in an utterance is coded individually (i.e., deletion of one sound in a cluster is coded as a deletion for that specific sound only).
13. /d/ for /th/ in the word “the” will always be interpreted as a sound substitution, regardless of the surrounding context.
14. Substituting “a” for “the” or the reverse is coded as a word substitution.

15. For categorization as a whole word repetition, words must occur adjacent to one another.
16. Diacritics indicating an unreleased sound or aspiration are not coded as errors. Otherwise, a diacritic in the proximity of a symbol indicates a perceptual difference from target and should be coded as an error (i.e., distortion).
17. An additional sound (i.e. a slight schwa insertion or a slight production of the initial sound) should be coded as an additional sound.
18. When making judgments for coding the following are acceptable:
    a. /I/ for "schwa" in unstressed syllables (e.g., gloomily)
    b. syllabic /n/ and syllabic /l/ for /ən/ and /əl/ respectively
    c. /n/ for / ŋ / when preceding a velar phoneme (e.g., Frank)
    d. Productions that contain an error and are self-corrected or productions that are begun but then contain a pause and are then re-started are not entered into any analyses.
19. Whole word repetition (words must occur adjacent to one another)

Note: In total counts, anticipation or perseveration additions are not counted towards the relevant error type (i.e., anticipation or perseveration) because these could not be taken into consideration when determining phonological error opportunities for the target stimuli.

APPENDIX E

CRITERIA, EXAMPLES AND DEFINITIONS FOR ERROR CATEGORIZATION

1. Inclusion/exclusion criteria for analysis eligibility. Target stimulus for all examples is: Frightened Fred fries fresh flour.
    a. For an utterance to be considered for analysis it must have the same number of syllables as the target stimulus.

Inclusion example:

Production: Frightened Fred fries fresh f*r*our

Rationale: There is a sound error, but the target has the correct number of syllables.

Exclusion example:

Production: Frightened Fred fries flour

Rationale: Too few syllables occur in the production.

   b. The critical variable is that each word in the produced utterance must have the same number of syllables as the target unit from the stimulus. Target stimulus: Frightened Fred fries fresh flour.

      Inclusion example:

      Production: Frightened Fred f*l*ies dry flour

      Rationale: There is a sound and a word error, however, the number of syllables is maintained.

      Exclusion example:

      Production: Fit Freddy fries fresh flour

      Rationale: The production has the right number of syllables however the first produced word only has one syllable whereas the first word in the target utterance has two syllables. The second word in the production has two syllables whereas in the target the second word has only one syllable.

2. The following categories were used to categorize sound and word errors.

   a. Sound errors: anticipations, perseverations, exchanges, ambiguous (anticipation-perseveration), distorted anticipations, distorted perseverations, distorted additions, sound substitutions, distorted sound substitutions, deletions, and additions.

   b. Word errors: word substitutions, word anticipations, word perseverations, and word exchanges.

3. General Definitions
    a. Sound error – a sound production unit that is perceptually identified as different from the target sound unit in the stimulus item at either a phonemic or sub-phonemic level.
    b. Word error - forms a real word that may or may not have been present in the original stimulus item (usually of the same grammatical class as the target word, but not always). Additionally, words that borrow a word stem from a target word that was present in the original stimulus are considered word errors. Exceptions to this rule are word errors that may have resulted from the slip of one sound, especially sounds experimentally manipulated to induce phonological errors. Word errors occur when the resulting unit could not have solely arisen from the movement of phonological segments from elsewhere in the phrase.

       Target stimulus for both examples is: The flighty fleeing flea flew free

       Inclusion example: The flighty fleeing bug flew free
       Exclusion example: The flighty fleeing f*r*ee flew free
       Rationale: The word "free" is in error, however, the error may have been caused by a sound from another word in the target.
    c. Non-word error – does not form a real word and does not occur simply as a result of movement of sounds in the target. Thus, word-like errors that may have formed from a contextual interaction with sounds from other words in the target utterance (i.e. anticipations, perseverations, exchanges) are not considered non-words.

Target stimulus: grim grizzly grabbed

Inclusion example: “faish grizzly grabbed”

Exclusion example: “g*liz* grizzly grabbed”

Rationale: The /l/ in “gliz” is considered anticipatory and so is the “iz.”

4. Sound Error Definitions
    a. Anticipation – “all intended occurrences of the intruding constituent are after the target location” (Dell, Burger, & Svec, 1997, p. 145).
    b. Perseveration – “all intended occurrences are before” the target location (Dell, et al., 1997, p. 145).
    c. Exchange – two sounds substitute for each other
    d. Ambiguous - errors for which there is an equidistant preceding and following potential error source, thus making the error causing agent uncertain
    e. Distortion – a production that is different from the target at a sub-phonemic level

Examples:

Target stimulus: Gleeful Glen glued the glass grape.

Anticipation example: Gleeful Glen glued the g*r*ass grape

Rationale: /r/ in grape error source for erred /r/ production in target “glass”

Perseveration example: Gleeful Glen glued the glass g*l*ape

Rationale: /r/ in glass errors source for erred /l/ production in target “grape”

Target stimulus: The grim grizzly grabbed grimey glue

Exchange example: “The grim grizzly grabbed g*l*imey g*r*ue”

Rationale: /l/ and /r/ changed places from target

Ambiguous: “The grim grizzly glabbed g*l*imey glue”

Rationale: The erred /l/ production for target “grimey” had two potential sources. First source: erred /l/ produced in “grabbed”; Second source: /l/ in target “glue.” Both sources are an equidistant number of phonemes from the error.

APPENDIX F

ERROR CODING RELIABILITY

In addition to transcription reliability, inter-rater reliability was obtained for error coding by the author and a graduate student trained by the author. Training consisted of reviewing the coding rules and definitions of error types and reviewing selected target productions previously coded by the examiner that were not on the randomly pre-selected list of tokens to be used for reliability judgments. Inter-judge reliability for error coding was based on three (25%) randomly selected, erred experimental stimuli from each of the three self-manipulated speaking rates, for each of four (25%) randomly selected participants from each participant group. This resulted in a total of nine sentences for each of the eight participants. Point-to-point reliability judgments were made for phonological error types (anticipations, perseverations, exchanges), non-serial order errors (i.e., distortions) and for the combined error types. Reliability judgments were calculated by dividing the number of agreements by the number of agreements plus the disagreements.

APPENDIX G

ERROR CODING RELIABILITY RESULTS

For error coding reliability, results were calculated and are presented relative to participant group (NBD, PWA), speaking rates (typical, fast, and faster) and error types (serial order phonological errors and non-serial order errors). For these reliability data error types were categorized as serial order phonological errors (i.e., anticipations, exchanges, and perseverations) and non-serial order errors (e.g., non-serial order distortion errors, sound substitutions, word errors, etc.). Point-to-point inter-rater reliability for error coding was 82% when participant groups (NBD, PWA), speaking rates (typical, fast, and faster), and error types (serial order phonological and non-serial order errors) were combined. When data from both participant groups was combined for both error types, point-to-point inter-rater reliability for the three speaking rates was 78%, 84%, and 82% (M = 81%) for the typical, fast and faster speaking rates, respectively. Point-to-point inter-rater reliability was 100% for NBD participants regardless of rate or error type. For PWA, error coding reliability averaged 70% (range across speaking rates was 53% – 79%) for serial order phonological errors and 73% (range across speaking rates was 58% – 83%) for non-serial order errors. Error coding reliability for PWA averaged 71% when error types were combined (range across speaking rates was 67% -77%). See Table 1 in this Appendix for a summary of the error coding reliability data.

Table G13: Percent inter-rater agreement for each participant group, by speaking rate, for serial order phonological and non-serial order errors

	Serial Order Phonological Errors		Non-Serial Order Errors		Combined Error Types	
	NBD	PWA	NBD	PWA	NBD	PWA
Typical	100	79	100	58	100	67
Fast	100	75	100	78	100	77
Faster	100	53	100	83	100	69
Average	100	70	100	73	100	71

APPENDIX H

GUIDELINES FOR DETERMINING PHONOLOGIC ERROR OPPORTUNITIES

1. An internet dictionary http://www.onelook.com that allows one to enter letter combinations to find all words with that combination was used to assist in determining whether a sound combination occurred in American English. All potential grapheme combinations for a particular sound combination were investigated. If there was no word that was not an abbreviation, acronym or proper name it was concluded that the sound combination does not occur in standard American English. The search goes through several dictionaries and encyclopedias to look for the grapheme combinations. This procedure was used to confirm that a particular sound combination does not occur in American English.
2. Anticipation, perseveration or exchange errors can occur within a word as well as between or across words.
3. Phonological opportunities were defined by the possibility of movement within the phonological constraints of American English. Whether or not the movement was likely to occur was not a consideration.

4. An opportunity is not counted if movement of the sound to a particular location would create a phonotactic error (e.g., voiced sound moved before a voiceless sound would indicate that the voiceless sound should become voiced and thus create another error). Example: final /ps/. Movement of a /b/ to the /p/ position as either any type of errors would mean that to be phonotactically accurate for American English, the /s/ should become a /z/. (i.e., “taps” would change to “tabz.” If the final sound remained /s/ then this would need to be coded as an error in the participant transcription).
5. An unstressed central vowel cannot occur in isolation.
6. An unstressed central vowel may not move to a stressed syllable position (i.e. a position in which the unstressed central vowel would become a stressed central vowel).
7. Lax vowels cannot terminate an open unstressed syllable (except schwa).
8. When “y” occurs at the end of an adjective (i.e., classy) or adverb, it will be transcribed as /I/ and interpreted as /I/ for determining coding and error opportunities.

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APPENDIX I

ACOUSTIC GUIDELINES

Instructions for digitizing the sound files:

1. Capture from the beginning of the beep to one-second post-production for the sound file. If one second is not available, go as far as you can to make sure that you have not eliminated any possible continuation of the utterance.
2. Use information from both the wave and the spectrogram to guide measurement decisions.
3. You are making two measurements:
    a. vocal reaction time – time from the offset of the beep to the initiation of vocal production
    b. total duration – from the initiation to termination of production of the experimental sentence.

Instructions for making acoustic measurements:

Spectrographic Analysis: wide band

Guidelines:

- Only utterances that are preceded by a beep need to be analyzed as these are the only sentences produced by study participants. Each sentence to be analyzed will occur one time in each of the three rate conditions.
- Use narrow band spectrogram to help make decisions by viewing formants
- Use energy level spectrum to help determine when sound energy drops below a certain level (i.e., 40dB)
- View voice bar and check to see if any speech like quality in helping to make judgments about sound initiation or termination.
- Incorporate aspiration in measurement when no clear boundaries exist

<u>Vocal Reaction Time (VRT) measurements</u>:

The widest waveform-spectrogram window used to make this measurement should be no larger than about 10 ms. before the beep until 100 ms. into the speech signal.

<u>Total Duration (TD) measurements</u>

In the waveform or spectrogram window there should be no more than one second of time represented. If the first cursor is placed at the extreme left of the screen and the second cursor at the extreme right of the screen the amount of time represented should not be more than one second..

APPENDIX J

ACOUSTIC MEASUREMENT RELIABILITY

Measurement

The examiner and one graduate student research assistant trained by the examiner made all acoustic (vocal reaction time and response duration) measurements. Training consisted of reviewing the procedures for making acoustic measurements and practice items. Point-to-point inter- and intra- judge reliability were calculated on the VRT and syllables per second measurements of approximately 17% of the target stimuli. Six sentences (two from each of the speaking rates) were pseudo-randomly chosen for reliability for NBD participants and at least one from each rate when possible for PWA. Additionally, for each rate and participant group, descriptive statistics for reliability tokens were calculated. Correlation analyses and absolute difference measurements were used to measure inter- and intra-rater reliability. A Pearson Product Moment Correlation coefficient of .80 or above was used as the criteria for acceptable inter- and intra- judge reliability for the correlation analyses. All correlation coefficients were computed using Pearson Product Moment correlations unless the normalcy assumption was not met, in which case the Spearman Rank Order correlation coefficient was computed. For each participant group, inter-rater reliability was further evaluated by calculating the average absolute difference and the percentage of the mean accounted for by that difference for each measurement type (vocal reaction time, syllables per second) at each speaking rate. The alpha level for tests of difference was set at .05.

Reliability Data

Both inter- and intra-rater reliability for the VRTs across all three speaking rates yielded Pearson and Spearman Rho correlation coefficients that ranged from .97 to 1.0. See Tables J1 and J2 this Appendix. The inter- and intra-rater reliability across all three speaking rates for syllables per second ranged from .98 to 1.0. See Tables J3 and J4 in this Appendix. All correlations were positive and using Cohen's (1988) guidelines**,** all effect sizes are considered large.

In order to assess the amount of error in judgments, the Intraclass Correlation coefficient (ICC) was calculated at each of the three speaking rates to assess inter- and intra-rater reliability for vocal reaction time and syllables per second measurements for both participant groups. The ICC is calculated as a "ratio of the variance of interest over the sum of the variance of interest plus error" (Shrout & Fleiss, 1979) (p. 420). This analysis used a Two-Way mixed effects model. The ICC was high and positive for all results with a range from .96 to 1.0. See this Appendix, Tables J1 - J4. In this Appendix, Tables J1 and J2 present inter- and intra-rater reliability ICCs for both participant groups for VRT while Tables J3 and J4 present inter- and intra-rater reliability ICCs for both participant groups for syll./secs.

As a further assessment of measurement accuracy, the absolute difference in ms. between the acoustic measurements of the raters and the percentage of the mean accounted for by those differences was computed for both participant groups for all three speaking rates. For VRT the average difference between raters in ms. ranged from .000 to .008 ms., which represented zero to one percent of the mean. For syllables per second, the average difference between raters ranged from .004 to .032 ms., also representing zero to one percent of the mean. See this Appendix, Tables J5 and J6 for a summary of absolute difference results for VRT and syllables per second results, respectively.

Table J14: Inter- rater reliability – Pearson, Spearman Rho and Intra-class (ICC) correlation coefficients for VRT

NBD

Speaking Rate	df	Correlation Coefficient	ICC	p value
Typical	30	.97	.99	.00
Fast	30	1.0	1.0	.00
Faster	30	1.0	1.0	.00

PWA

Rate	df	Correlation Coefficient	ICC	p value
Typical	22	1.0	1.0	.00
Fast	21	1.0	.99	.00
Faster	20	1.0	1.0	.00

Table J15: Intra- Rater Reliability - Pearson, Spearman Rho and Intra-class (ICC) correlation coefficients for VRT

NBD

Rater	df	Typical		df	Fast		df	Faster	
		r	ICC		r	ICC		r	ICC
Rater 1	29	.98	.99	29	.99	.99	30	1.00	1.00
Rater 2	29	.98	.99	29	.97	.96	30	1.00	1.00

PWA

Rater	df	Typical		df	Fast		df	Faster	
			ICC		r	ICC		r	ICC
Rater 1	22	.99	.99	20	1.00	1.0	20	.99	.98
Rater 2	22	1.00	1.0	20	1.00	1.0	20	.99	.99

Table J16: Inter -rater reliability – Pearson, Spearman Rho and Intra-class (ICC) correlation coefficients for syllables per second

NBD

Rate	df	Correlation Coefficient	ICC	p value
Typical	30	1.0	1.0	.00
Fast	30	1.0	1.0	.00
Faster	30	1.0	.99	.00

PWA

Rate	df	Correlation Coefficient	ICC	p value
Typical	22	1.00	1.0	.00
Fast	21	1.00	1.0	.00
Faster	20	.98	1.0	.00

Table J17: Intra– rater reliability - Pearson, Spearman Rho and Intra-class (ICC) correlation coefficients syllables per second

NBD

Rater	df	Typical		df	Fast		df	Faster	
		r	ICC		r	ICC		r	ICC
Rater 1	29	1.00	1.00	29	.99	.99	30	.99	.99
Rater 2	29	1.00	1.00	29	.98	.98	30	1.00	1.00

PWA

Rater		Typical			Fast		df	Faster	
		r	ICC		r	ICC		r	ICC
Rater 1	22	1.00	1.00	20	1.00	1.00	20	1.00	1.00
Rater 2	22	1.00	1.00	20	1.00	1.00	20	1.00	1.00

Table J18: Inter-rater reliability differences in ms. for vocal reaction time (VRT) and percentage of mean for which difference accounts

Rate	NBD				PWA			
	VRT1	VRT2	Diff. in ms	Percent of mean	VRT1	VRT2	Diff. in ms	Percent of mean
Typical	.553	.554	.001	0	.720	.728	.008	1
Fast	.430	.430	.000	0	.637	.644	.007	1
Faster	.401	.401	.000	0	.556	.557	.001	0

Table J19: Inter-rater reliability differences in ms. for syllables per second (syll/sec) and percentage of mean for which difference accounts

Rate	NBD				PWA			
	Syl/sec1	Syl/sec2	Diff. (ms)	Percent of mean	Syl/sec1	Syl/sec2	Diff (ms)	Percent of mean
Typical	2.678	2.682	.004	0	2.477	2.493	.016	1
Fast	4.087	4.119	.032	1	2.612	2.620	.008	0
Faster	4.338	4.362	.024	1	3.058	3.082	.024	1

APPENDIX K

ERROR CATEGORIES

Table K20: Error summary for non-brain damaged (NBD) participants at the typical speaking rate for all error categories

Typical	[a]Phon. Errors	[b]Dist. Phon. Errors	[c]Ambig. Phon. Errors	Sound Distortions	Sound Substitutions	Sound Deletions	Sound Additions	Word Errors	Non-word Errors
1	3	0	0	1	1	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	5	0	0	0	2	1	0	2	0
4	5	0	1	2	3	2	1	3	0

Table K1 (continued)

5	2	0	0	0	3	0	0	0	0
6	2	0	0	6	0	0	2	1	0
7	1	0	0	0	1	0	0	3	0
8	1	0	0	9	1	0	0	0	0
9	3	0	0	3	0	0	1	1	0
10	8	0	0	2	2	2	2	3	0
11	2	0	0	3	0	0	0	1	0
12	5	0	0	1	0	1	0	1	0
13	3	0	0	4	1	1	0	2	0
14	3	0	0	2	2	0	1	1	0
15	2	0	0	0	6	0	1	2	0
16	0	0	0	0	1	0	2	2	0

Note. [a]Phon = phonological; [b]Dist = distortion; [c]Ambig = Ambiguous

Table K21: Error summary for non-brain damaged participants at the fast speaking rate for all error categories

Fast	[a]Phon. Errors	[b]Dist. Phon. Errors	[c]Ambig. Phon. Errors	Sound Distortions	Sound Substitutions	Sound Deletions	Sound Additions	Word Errors	Non-word Errors
1	4	0	1	5	2	1	1	2	0
2	11	0	0	2	0	0	2	1	0
3	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
4	5	0	0	2	0	5	2	0	0
5	0	0	0	0	0	0	0	0	0
6	16	0	2	9	2	6	2	1	0
7	1	0	0	1	0	0	0	1	0
8	2	0	1	3	1	2	0	2	0
9	11	0	2	0	3	5	1	0	2
10	4	0	0	1	4	4	1	5	0
11	12	1	0	7	3	5	1	2	0
12	15	2	1	7	4	2	1	0	0

Table K2 (continued)

13	5	0	0	1	[e]2	1	0	3	0
14	5	0	0	0	2	1	0	0	0
15	4	0	0	2	3	3	1	1	0
16	3	0	0	2	0	0	1	2	1

Note. [a]Phon = phonological; [b]Dist = distortion; [c]Ambig = Ambiguous; [d] = Missing data; [e] = one distorted sound substitution

Table K22: Error summary for non-brain damaged participants at the faster speaking rate for all error categories

Faster	[a]Phon. Errors	[b]Dist. Phon. Errors	[c]Ambig. Phon. Errors	Sound Distortions	Sound Substitutions	Sound Deletions	Sound Additions	Word Errors	Non-word Errors
1	0	0	0	0	0	1	0	0	0
2	5	0	0	1	1	1	0	0	0
3	1	0	0	0	0	0	1	0	0
4	8	0	3	0	1	5	1	0	0
5	3	0	0	0	0	2	1	0	0
6	4	0	1	4	4	4	0	0	0
7	0	0	0	0	0	0	0	0	0
8	2	0	1	1	0	1	2	0	0
9	3	0	1	0	1	1	0	0	0
10	4	0	2	0	0	3	0	1	0
11	3	0	0	4	1	4	0	0	0
12	5	1	0	5	1	4	0	0	0
13	0	0	1	0	0	0	0	0	0

14	8	0	1	3	3	3	0	0	0
15	1	0	0	0	0	3	0	0	0
16	1	0	0	0	1	0	0	0	0

Note. [a]Phon = phonological; [b]Dist = distortion; [c]Ambig = Ambiguous

Table K23: Error summary for persons with aphasia (PWA) at the typical speaking rate for all error categories

Typical	[a]Phon. Errors	[b]Dist. Phon. Errors	[c]Ambig. Phon. Errors	Sound Distortions	Sound Substitutions	Sound Deletions	Sound Additions	Word Errors	Non-word Errors
1	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
2	3	0	0	2	1	1	0	1	0
3	0	0	0	0	0	0	0	2	0
4	0	0	0	0	0	0	0	1	1
5	1	0	0	1	0	0	0	2	0
6	7	0	2	1	6	4	7	3	4
7	1	1	2	0	7	6	2	3	7
8	12	0	0	1	6	7	6	7	6
9	1	0	0	0	2	0	2	4	0
10	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
11	0	0	0	1	0	0	0	7	0
12	1	0	0	1	1	0	0	7	0

Table K4 (continued)

13	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
14	1	0	0	0	0	1	0	0	1
15	10	0	0	0	4	5	1	0	1
16	4	0	2	3	5	2	8	0	0

Note. [a]Phon = phonological; [b]Dist = distortion; [c]Ambig = Ambiguous; [d] = No data

Table K24: Error summary for persons with aphasia (PWA) at the fast speaking rate for all error categories

Fast	[a]Phon. Errors	[b]Dist. Phon. Errors	[c]Ambig. Phon. Errors	Sound Distortions	Sound Substitutions	Sound Deletions	Sound Additions	Word Errors	Non-word Errors
1	1	0	0	0	0	0	0	0	0
2	10	1	1	3	2	2	1	0	0
3	0	0	0	0	0	0	0	1	0
4	2	0	0	2	3	0	2	5	1
5	0	0	0	0	0	0	0	0	0
6	2	0	0	3	6	7	2	1	0
7	0	0	0	0	0	0	0	1	0
8	1	0	3	0	0	4	2	3	3
9	3	0	0	0	1	0	2	2	0
10	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
11	1	0	0	0	0	0	0	1	0
12	0	0	0	1	0	0	0	1	0

Table K5 (continued)

13	1	0	0	0	2	2	0	7	0
14	1	0	0	0	0	2	1	0	0
15	2	0	1	0	1	0	1	5	0
16	8	0	0	2	7	2	3	3	1

Note. [a]Phon = phonological; [b]Dist = distortion; [c]Ambig = Ambiguous; [d] = No data

Table K25: **Error summary for persons with aphasia (PWA) at the faster speaking rate for all error categories**

Faster	[a]Phon. Errors	[b]Dist. Phon. Errors	[c]Ambig. Phon. Errors	Sound Distortions	Sound Substitutions	Sound Deletions	Sound Additions	Word Errors	Non-word Errors
1	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
2	0	0	0	1	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	3	0	0	0	0	1	0	0	0
5	0	0	0	0	1	0	0	1	0
6	0	0	0	1	1	3	0	0	0
7	2	0	0	0	6	3	0	0	1
8	3	0	0	0	2	3	0	1	1
9	0	0	0	0	2	0	0	1	0
10	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
11	1	0	0	0	0	0	2	1	0
12	0	0	0	0	1	0	0	5	0

Table K6 (continued)

13	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
14	0	0	0	0	0	0	0	5	1
15	3	0	1	1	2	1	0	0	0
16	4	0	0	1	3	1	2	2	0

Note. [a]Phon = phonological; [b]Dist = distortion; [c]Ambig = Ambiguous; [d] = No data

APPENDIX L

AVERAGED ARCSINE TRANSFORMED DATA FOR ALL PARTICIPANTS

Table L26: Averaged arcsine transformed data for anticipation, exchange, and perseveration error types, used to form serial order error ratios for the non-brain damaged participants at each speaking rate

Participant	Typical			Fast			Faster		
	[a]Ant	[b]Ex	[c]Per	[a]Ant	[b]Ex	[c]Per	[a]Ant	[b]Ex	[c]Per
1	0.207	0.216	0.243	0.218	0.203	0.196	0.158	0.228	0.189
2	0.158	0.202	0.196	0.243	0.292	0.227	0.255	0.26	0.219
3	0.205	0.233	0.211	[d]	[d]	[d]	0.291	0.235	0.189
4	0.277	0.21	0.202	0.261	0.225	0.249	0.399	0.215	0.192

Table L1 (continued)

5	0.171	0.179	0.204	0.173	0.251	0.235	0.2	0.276	0.187
6	0.234	0.211	0.21	0.369	0.261	0.233	0.341	0.244	0.19
7	0.213	0.198	0.194	0.196	0.184	0.188	[d]	[d]	[d]
8	0.184	0.209	0.205	0.227	0.2	0.21	0.206	0.279	0.184
9	0.198	0.304	0.218	0.279	0.217	0.258	0.393	0.347	0.172
10	0.24	0.24	0.306	0.226	0.205	0.215	0.357	0.221	0.257
11	0.21	0.224	0.217	0.213	0.222	0.288	0.278	0.219	0.18
12	0.211	0.247	0.264	0.275	0.23	0.304	0.337	0.207	0.235
13	0.171	0.266	0.253	0.219	0.207	0.214	0.162	0.214	0.176
14	0.179	0.22	0.209	0.215	0.231	0.209	0.257	0.231	0.209
15	0.212	0.198	0.204	0.176	0.229	0.225	0.196	0.198	0.172
16	0.15	0.194	0.181	0.207	0.207	0.221	0.19	0.216	0.198
Mean	0.201	0.222	0.220	0.233	0.224	0.231	0.268	0.239	0.197
SD	0.033	0.031	0.032	0.049	0.027	0.032	0.082	0.038	0.024

Note. [a]Ant = Anticipations; [b]Exch = Exchange; [c]Persev = Perseverations; [d]Missing data

Table L27: Averaged arcsine transformed data for anticipation, exchange, and perseveration error types used to form serial order error ratios for the persons with aphasia at each speaking rate

Participant	Typical			Fast			Faster		
	[a]Ant	[b]Ex	[c]Per	[a]Ant	[b]Ex	[c]Per	[a]Ant	[b]Ex	[c]Per
1	d	d	d	0.35	0.22	0.201	d	d	d
2	0.15	0.227	0.246	0.289	0.205	0.217	0.17	0.232	0.232
3	0.19	0.178	0.238	0.029	0.05	0.032	d	d	d
4	0.155	0.22	0.21	0.258	0.212	0.184	0.782	0.306	0.306
5	0.411	0.245	0.197	0.134	0.143	0.161	0.17	0.245	0.245
6	0.244	0.205	0.269	0.189	0.188	0.217	0.17	0.226	0.226
7	0.202	0.169	0.249	0.155	0.194	0.163	0.24	0.204	0.204
8	0.33	0.218	0.322	0.246	0.222	0.208	0.342	0.222	0.222
9	0.214	0.212	0.212	0.323	0.171	0.192	0.16	0.204	0.204
10	d	d	d	d	d	d	d	d	d
11	0.151	0.226	0.204	0.265	0.22	0.21	0.162	0.262	0.262
12	0.232	0.206	0.204	d	d	d	d	d	d

Table L2 (continued)

13	[d]	[d]	[d]	0.145	0.22	0.289	[d]	[d]	[d]
14	0.17	0.595	0.197	0.411	0.245	0.197	0.206	0.306	0.306
15	0.273	0.265	0.248	0.207	0.261	0.21	0.344	0.213	0.213
16	0.275	0.275	0.26	0.277	0.233	0.235	0.258	0.226	0.226
Mean	0.231	0.249	0.235	0.234	0.199	0.194	0.273	0.241	0.241
SD	0.077	0.108	0.036	0.099	0.052	0.056	0.182	0.036	0.036

Note. [a]Ant= Anticipations; [b]Exch = Exchange; [c]Persev = Perseverations; [d]No data

APPENDIX M

TOTAL NUMBER AND PERCENTAGE OF SOUND ERRORS FOR ALL PARTICIPANTS

Table M28: Total *number* of sound errors for non-brain damaged (NBD) participants and persons with aphasia (PWA) for each speaking rate condition

NBD				PWA			
Participant	Typical	Fast	Faster	Participant	Typical	Fast	Faster
1	5	14	1	1	[b]	1	[b]
2	0	17	8	2	7	14	1
3	8	[a]	2	3	0	0	0
4	14	14	18	4	0	9	4
5	5	0	8	5	2	0	1
6	10	38	17	6	27	20	5
7	2	2	2	7	20	0	11
8	2	11	7	8	33	10	10
9	7	22	6	9	5	6	2
10	16	4	9	10	[b]	[b]	[b]

Table M1 (continued)

11	5	29	12	11	1	1	3
12	7	30	16	12	3	1	1
13	9	9	1	13	[b]	5	[b]
14	8	9	18	14	2	4	0
15	10	13	4	15	20	5	8
16	3	6	2	16	24	22	11
Mean	6.94	15.2	8.19		11.08	6.53	4.38
SD	4.33	10.6	6.26		11.87	7.20	4.21

Note. [a] = Missing data; [b] = No data

Table M29: *Percentage* of total sound errors per utterance for non-brain damaged (NBD) participants and persons with aphasia (PWA) for each speaking rate condition

NBD				PWA			
Participant	Typical	Fast	Faster	Participant	Typical	Fast	Faster
1	0.50	0.82	0.50	1	[b]	1.00	[b]
2	0.00	2.43	1.33	2	1.00	0.88	0.33
3	0.57	[a]	1.00	3	0.00	0.00	0.00
4	1.56	1.56	2.57	4	0.00	1.80	4.00
5	0.50	0.00	1.33	5	2.00	0.00	1.00
6	1.43	2.92	4.25	6	2.45	2.86	2.50
7	0.50	0.40	0.00	7	2.86	0.00	3.67
8	.20	1.38	1.40	8	3.67	2.50	2.50
9	1.78	1.27	3.00	9	1.25	1.50	1.00
10	.63	1.61	2.00	10	[b]	[b]	[b]
11	1.17	2.00	3.20	11	0.50	0.50	1.50
12	1.33	2.00	2.20	12	0.60	[b]	[b]
13	1.00	0.60	0.25	13	[b]	1.67	[b]
14	0.80	0.90	1.64	14	2.00	4.00	0.00
15	1.00	0.81	0.80	15	2.00	0.83	2.67
16	0.30	0.50	0.29	16	3.43	2.20	1.57
Mean	.81	1.24	1.66		1.36	1.23	1.3
SD	.50	0.79	1.24		1.29	1.21	1.39

Note. [a] = Missing data; [b] = No data

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