University of Reading

Influence of Linguistic, Speech Motor, and Executive Control Processes in People with Aphasia, Healthy Younger Adults, and Healthy Older Adults

Thesis presented for the degree of Doctor of Philosophy

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

Mariam AlOrifan

February 2020

"In examining disease, we gain wisdom about anatomy and physiology and biology. In examining the person with disease, we gain wisdom about life."

Oliver Sacks

Acknowledgements

This thesis is the culmination of my PhD journey of which was just like climbing a high peak, step by step, accompanied with encouragement, hardship, trust, and frustration. When I found myself at top experiencing the feeling of fulfillment, I realized though only my name appears on the cover of this dissertation a great deal of people including my family members have contributed in the accomplishment of this huge task.

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Abstract

Word production is an essential feature for successful communication where semantic information of a word is activated first, followed by the activation of the targeted words' phonological form, finalized by word articulation. Existing research has largely concentrated on the lexical-semantic processes of word retrieval in speech production, however, the interaction of word production processes- linguistic and speech motor - and the influence they have on one another during word production in the healthy older population and people with aphasia has been rarely addressed. Moreover, beyond language, there is increasing agreement that the broader cognitive profile of aphasia can influence the manifestation of linguistic impairment. Furthermore, the nature of linguistic deficits in people with aphasia and their relationship to speech motor and executive control mechanisms is not established in the literature.

This thesis aimed at exploring the relationship between linguistic, speech motor, and executive control processes on healthy younger adults, healthy older adults, and people with aphasia. The exploration of the research aim followed in a systematic and stepwise structure in two phases. Phase one, measured the influence of linguistic and speech motor process on word production during a picture naming task on healthy younger and healthy older adults (Chapter 2) and participants with aphasia (Chapter 3). Phase two investigated the relationship amongst linguistic, speech motor, and executive control processes on healthy younger and healthy older adults (Chapter 4) and in the participants with aphasia (Chapter 5) where the participants completed one linguistic task (picture naming) and six executive control tasks (inhibitory measures: Word colour and spatial Stroop, Updating measure: N-back and digit span, Switching measure: Same different and Trail Making Test).

In Chapter 2, compared to healthy younger adults, the healthy older adults performed significantly poorer on all the word production measures (Accuracy, RT, WD). No interactions between linguistic and speech motor processes was indicated in this chapter, however, linguistic and speech motor processes influenced one another on word production measures. Findings for Chapter 3 revealed that people with aphasia demonstrated significantly poorer on all word production measures as compared to the healthy controls. The influence of linguistic and speech motor processes on one another was indicated on word production measures. Additionally, significant associations amongst linguistic, speech motor, and executive control abilities was found. Chapter 4 indicated no significant correlations between the word production measure and the executive control measures on the healthy younger adults. The healthy older adults demonstrated significant correlations amongst executive control measures and measures of word production. Both groups of participants in Chapter 5 demonstrated significant correlations between the measures of executive control and word production. Taken together, findings revealed important insight into the broader linguistic-speech motor- executive control profile for the healthy older adults and participants with aphasia and the theoretical and therapeutic implications.

Chapter 1

General Introduction

1.1 Introduction

The ability to communicate effectively and efficiently in everyday life is dependent on the rapid access to and successful production of words. A simple concept such as the production of a single word is achieved through the composite complex interaction of multiple linguistic, speech motor, and executive control processes. However, most research on word production, on healthy and impaired populations, has focused on the individual impact of linguistic, speech motor, and executive control mechanisms on word production separately and independently.

Theoretical models of spoken word production claim that it is a multistage process which involves the coordination and interaction of two major levels of processing: conceptualisation and formulation. The first stage, conceptualisation, initiates the process with the activation of a particular lexical concept, while the second stage is the subsequent mapping of the abstract lexical form to its phonological structure (Dell, Burger, & Svec, 1997; Foygel & Dell, 2000; Levelt, 2001). Speech motor performance is depicted as a final processing level with little to no emphasis. Congruently, word production is a competitive process that requires the selection of the targeted word 'dog' from several other competing lexical items such as 'cat, fox, and tiger' (Levelt, Roelofs, & Meyer, 1999). Research has indicated that a set of higher order cognitive skills known as executive control mechanisms (executive functions) are crucial for the successful retrieval of words, and the resolution of possible competition. Empirical evidence has suggested that executive functions, such as inhibition, do in fact play a vital role in the resolving of the lexical competition during lexical access (Crowther & Martin, 2014; Shao, Roelofs, Martin, & Meyer, 2015). However, there is currently no consensus in the literature as to whether the aspects of word production mentioned above (conceptualisation, lexical access, semantics, phonology, and speech motor performance) as well as executive control functions have an influence on the process of ageing in both healthy individuals and those with aphasia.

This PhD research intends to investigate some of the outstanding issues in word production literature in the context of individuals with aphasia and healthy older participants. Specifically, this dissertation aims to investigate the relationship between linguistic, speech motor, and executive control processes in a systematic and stepwise exploration in two phases. In the first phase, outlined in Chapters 2 and 3, the interaction between linguistic and speech motor processes in word production was assessed on healthy younger and healthy older adults (Chapter 2) as well as people with aphasia (Chapter 3). A picture naming task was implemented with experimental manipulations of semantic contexts during lexical access as a measure of linguistic processing and articulatory complexity as a measurement of speech motor processes. Accuracy, reaction times (RT, hereafter), and word durations (WD, hereafter) were measured to investigate the possible interactions between linguistic and speech motor processes and the possible differences between healthy younger and healthy older adults, as well as people with aphasia.

As discussed above, models of word production generally agree that, in order to initiate the production of a word, a targeted concept must be activated. The concept is subsequently processed at the semantic level (comprising features of the targeted concept e.g. “furry” and “has a tail”), followed by the activation of the corresponding word units (abstract, unitary representations of semantic units associated with syntactic but not phonological information), and lastly, a phonological level where the targeted syllabic units are selected (e.g. units from /dog/). From here, information is then sent through phonetic and articulatory processing to complete production. Therefore, reaction times were utilised to measure linguistic processing and speech motor preparation, and WD for speech motor performance and articulatory execution (see Figure 1.1).

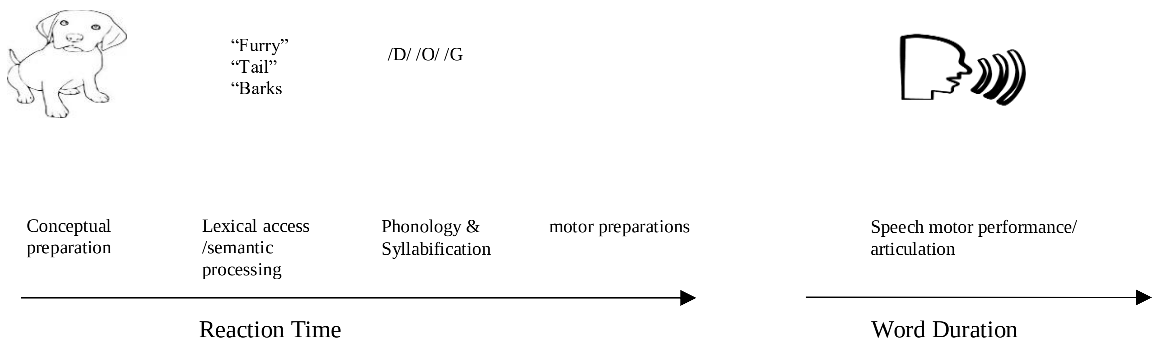


Figure 1.1 Sample of word production measures of reaction times and word durations for the word ‘dog’.

In the second phase, outlined in Chapters 4 and 5, we investigate the relationship between linguistic, speech motor, and executive control processes in healthy younger and healthy older adults (Chapter 4) and in people with aphasia (Chapter 5). We compared the performance of the participants on the word production task in the previous chapters to six different executive control tasks to determine the association between linguistic, speech motor, and executive control processes.

This introduction comprises a background on the evidence of the interactions between linguistic processes and speech motor control in healthy and impaired individuals, components of executive control processes, evidence of the interactions between linguistic and executive control processes in healthy and impaired individuals, discussion of the different methodological challenges in testing people with aphasia, and finally the overall aims of the thesis.

Aphasia is traditionally defined as an acquired neurological impairment characterised by the disruption of language functions manifested in a reduction in the availability of vocabulary, auditory comprehension, reading, oral-expressive language, and writing (Darley, 1982). Beyond the evident language impairments, there is increasing agreement that speech motor and cognitive impairments in individuals with aphasia do indeed influence the manifestation of their linguistic impairments (Scholl, McCabe, Heard, & Ballard, 2018). Sarno (1998) constructed a list of several significant factors that therapists working with people with aphasia must consider in order to provide the most effective and efficient interventions with favourable outcomes. Emphasis was put on the incorporation of language (inclusive of all modalities), speech motor control, and cognitive processes for all rehabilitation treatment on people with aphasia in order to produce favourable outcomes. Current and previous literature has identified the co-existence of speech motor deficits with aphasia and executive control deficits with aphasia to be significant (Kurowski & Blumstein, 2016; Nespoulous, Baqué, Rosas, Marczyk, & Estrada, 2013). However, minimal research has been done to measure the influence of speech motor deficits on linguistic processing in people with aphasia. Nor has any research been done to study the interaction of speech motor control and executive control deficits on people with aphasia and healthy ageing individuals.

The incidence of aphasia increases with age. Therefore, the implementation of tests on healthy older adults was crucial for the purpose of this dissertation as the assessment of linguistic, speech motor control, and executive functions on people with aphasia is conducted regularly in the clinical and research context. Those people with aphasia are often individuals in their fifties or older, so an assessment of the performance of healthy older adults in the same age range could be beneficial for both clinicians and researchers. Importantly, in order to enhance our knowledge on linguistic, speech motor control, and executive function deficits in people with aphasia, it was crucial to investigate the impact of healthy ageing on the performance of linguistic, speech motor control, and executive control functions.

1.1.1 Interaction of Linguistic and Speech Motor Control Processes

Empirical evidence for the influence of speech motor and linguistic processes has been assembled using a variety of methodologies such as perceptual, behavioural, acoustic, physiological, and kinematic on healthy and impaired children and adults. Researchers have also attempted to integrate earlier speech production models, both the psycholinguistic and motor speech control, to provide a comprehensive model depicting the association and influence of both linguistic and motor processes on speech production.

1.1.1.1 Models of word production. Traditional theoretical models of spoken word production are generally classified into two distinct categories: those that focus on aspects of linguistic processing (i.e., lexical access, syntax, semantics, phonology) and those that focus on speech motor control (i.e., neural programming, articulation). Models focusing on linguistic processing (Dell, 1986; Levelt et al., 1999) have agreed that spoken word production is comprised of two main stages, the first being the mapping of the conceptual forms of words to a stored abstract lexical form and the second being the subsequent mapping of the abstract lexical form to its phonological structure. Disturbances to either of these linguistic levels can instigate errors in speech output in both healthy and impaired individuals (Kittredge, Dell, Verkuilen, & Schwartz, 2008). In those models, speech motor performance is suggested to be a final processing level and little to no analysis of the linguistic/speech motor interface is provided (Bose, Colangelo, & Buchanan, 2011). On the other hand, models centring on speech motor control deal predominantly with neural programming circuits and articulatory kinematics with linguistic processing occurring upstream and independently of speech motor performance (Tourville & Guenther, 2011).

Recently, in an aim to integrate speech production approaches from the areas of psycholinguistics, neuroscience, and speech motor control, Hickok (2012, 2014) proposed the Hierarchical State Feedback Control model (HSFC). The model initiates similar to the psycholinguistic models, where speech production is instigated by the activation of a conceptual representation. Subsequently, a corresponding word (lemma) representation is selected. The word level (lemma) projects in parallel to both the auditory and motor sides of the highest cortical level of feedback control. This higher-level processing in turn projects, also in parallel, to the lower-level somatosensory cerebellum motor cortex loop where the phoneme system receives input from the somatosensory perceptual system, and where the syllable system receives input from the auditory system. In this loop, the associated motor programme is then selected with each of its component phonemes, and the targeted word is then articulated. In summary, Hickok proposes that there is direct mapping from the targeted concept to the lemmas and from the lemmas onto motor syllable and phoneme programmes for articulation (see Figure 1.2).

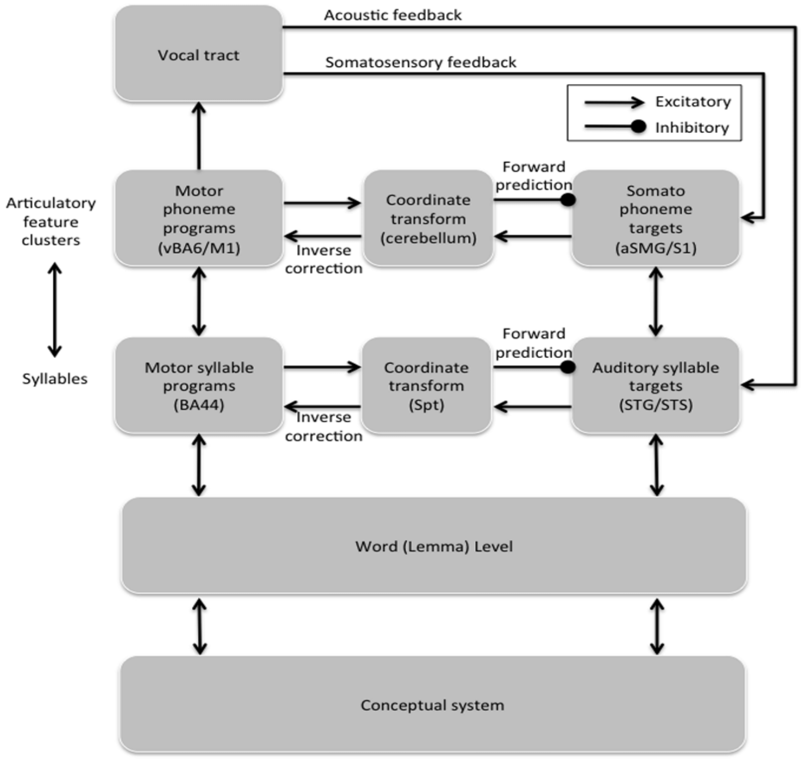


Figure 1.2 The hierarchical state feedback control model by Hickok (2012) which aims to integrate psycholinguistic and motor control models for word production.

The division of the theoretical models is unfortunate as there exists evidence for the bidirectional interaction between linguistic and speech motor processes from studies on heathy and impaired individuals.

1.1.2 Interaction of Linguistic and Speech Motor Processes in Healthy Children and Adults

Linguistic processing has been an intense focus of research for numerous years and this has accordingly generated rich experimental and theoretical literature. On the other hand, research involving the actual speech motor processes involved in word production has been more limited in scope. Even rarer is research that attempts to integrate and bridge the apparent gap between linguistic and speech motor processes.

Empirical data from typical and atypical populations have, using various methodologies, provided evidence that linguistic and speech motor processes are not as independent as originally thought, rather suggesting that there is an interplay between both processes (Bose, van Lieshout, & Square, 2007; Heisler, Goffman, & Younger, 2010). Correspondingly, previous studies on healthy and impaired children and adults that have measured the interaction of linguistic and speech motor processes through the manipulation of linguistic units such as syntax, phonology, and semantics while simultaneously measuring the changes in speech production and articulation have indicated that the manipulation of linguistic demands effected changes in articulatory properties.

In regard to healthy children and adults, Maner, Smith, and Grayson (2000) investigated the influence of utterance length and complexity on the speech motor performance of eight five-year-old children and eight young adults (ages ranging from 20 to 25). Their study measured the possible influences of utterance length and syntactic complexity on speech motor performance and articulatory movement stability. The participants in the study repeated sentences with low and high syntactic complexity while their lower lip movements and stability were measured. Their results indicated an increase in articulatory variability and a decrease in lip stability in longer and more complex sentences, with the children displaying more reduced stability than the adults.

Further, a study with healthy children by Kleinow and Smith (2006) provided similar results to the study mentioned above. The ten children (all nine years of age) in this study were asked to repeat utterances that were controlled for length and levels of syntactic complexity while simultaneously measuring articulatory variability. Syntactic complexity was manipulated by the addition of a relative clause to make the utterance complex and a conjunction to make the utterance simpler. For example, “The birds and the butterflies played by the pond” is considered simpler than “The birds that saw butterflies played by the pond”. The children showed more articulatory variability when repeating the complex sentences compared to the simpler ones.

Heisler and Goffman (2016) examined the influence of lexical-semantic (neighbourhood density) and phonological (phonotactic probability) levels on articulatory processing in 24 healthy children (mean age 4.5). Participants in this study repeated eight bisyllabic non-words: /pæptom/, /bompʌm/, /bɑftɛb/, /fospɪb/, /pʌmtæm/, /bʌfkɪp/, /fɑmkɪb/, and /mofpɛb/ while kinematic analyses were recorded for the opening and closing of the upper and lower lips. The words were divided into two groups with each group containing four words, two with syllables in a dense phonological neighbourhood and the other two with syllables in a sparse phonological neighbourhood. All the words in the first group had high frequency consonant sequences word medially and all words from group two had low frequency consonant sequences word medially. Kinematic analysis revealed that articulatory variability and stability decreased on words with low neighborhood density and low phonotactic probability. The results from this study demonstrate the interactivity between lexical, phonological, and articulatory processes.

The interactions between syntactic complexity and articulatory variability in the studies mentioned above support the conception that linguistic variables have a more direct effect on speech motor control and that children and adults with speech impairments may be more susceptible to motor deficiencies due to the increase of the linguistic loading. Likewise, the interactions between the neural systems responsible for language and for speech motor control have been frequently researched in healthy adults. Neuropsychological and neurophysiological research utilising fMRI, MRI, EEG, and CT scans suggest that there is functional overlap in the neural networks that process language and movement (Arbib, 2006; R. D. Kent, 2004). A study by Pulvermüller, Hauk, Nikulin, and Ilmoniemi (2005), used FMRI to show that the left hemispheric cortical systems for language and action were linked to each other and that processing semantically related words influenced the activation in motor and premotor areas. A more recent fMRI study conducted by Meinzer et al. (2014), yielded results suggesting that word retrieval in healthy individuals can improve when electrical stimulation to motor and language areas of the brain is provided.

Neuroimaging studies using MRI and fMRI imaging during silent reading of action words on healthy individuals have revealed meaning-related activation in the fronto-central motor system. When participants read words that refer to actions performed with the tongue, hands, or legs, such as “lick”, “pick”, and “kick”, it prompted the somatotopic activation of the motor and premotor cortices that are involved in the body parts contributing to word-related actions (de Lafuente & Romo, 2004; Hauk, Johnsrude, & Pulvermüller, 2004).

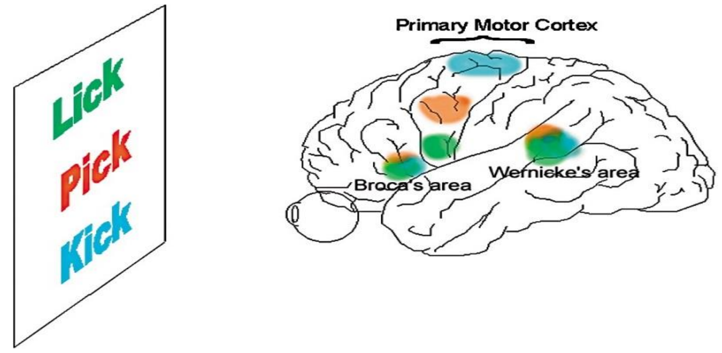


Figure 1.3 The activation of Cortical motor areas during the silent reading of action words (de Lafuente & Romo, 2004).

Consistent with the previous findings, two fMRI studies conducted by Pulvermüller et al. (2001) and Pulvermüller et al. (2005) on healthy middle-aged individuals presented similar results. When participants silently read and listened to action words that related to the face, arm and leg, there was somatotopic activation from the language motor regions to motor regions of the brain within tens of milliseconds. When participants read or listened to the word "grasp", areas of the motor cortices that are involved in the voluntary movement of the hand were activated, and areas of the motor cortices involved in voluntary movement of the feet were activated by leg-related action words such as "walk" (see figure 1.4).

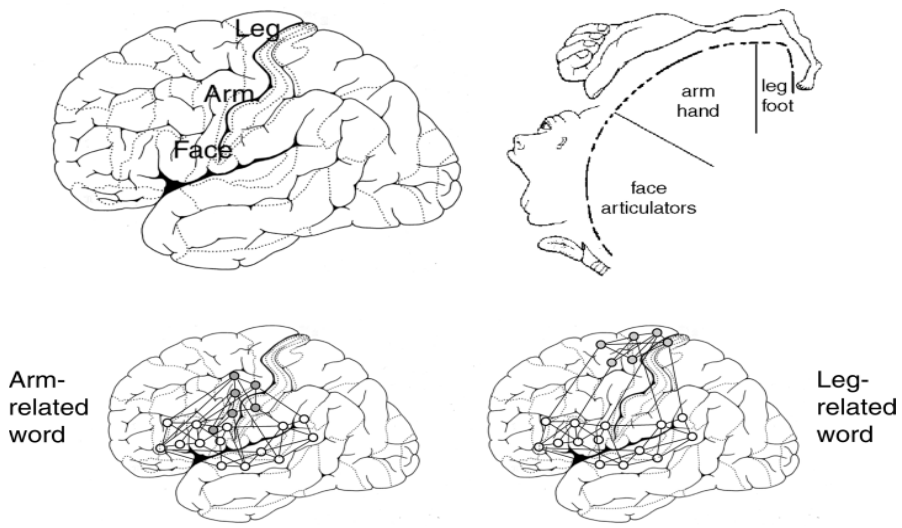


Figure 1.4 Neuronal activation over language areas and arm or leg motor and premotor cortex during the reading and listening of arm and leg words (Pulvermüller et al., 2005).

Similarly, research on word production in children and adults with speech impairments, such as stuttering, has indicated that linguistic and speech motor processes were found to interact in complex ways, with changes to lexical variables showing broadly distributed effects on motor output (Brumbach & Goffman, 2014; Smith, 2006; Walsh & Smith, 2011).

1.1.3 Evidence of the Interaction of Linguistic and Speech Motor Processes in Impaired Children and Adults

When it comes to stuttering, the interaction between linguistic and speech motor processes, specifically the influence of syntactic complexity on fluency of speech, provides evidence that as linguistic complexity (i.e., syntactic complexity) increases, speech motor processes are negatively affected. MacPherson and Smith (2013) examined the effect of the manipulation of sentence length and syntactic complexity on the speech motor control of children who stutter as compared to age-matched controls. The participants repeated sentences with varied lengths (8 -11 syllables) and syntactic complexity (presence or absence of a subject relative clause). Kinematic measures of articulatory variability and movement were analysed by tracking the movements of the upper lip, lower lip, jaw, and head. Results of their study indicated that sentence length and syntactic complexity strongly influenced the speech motor control of both groups of participants; however, the children who stutter demonstrated significantly more articulatory variability than the healthy controls.

Furthermore, (Smith, Sadagopan, Walsh, & Weber-Fox, 2010), measured the effects of phonological complexity on the speech motor performance of seventeen adults who stutter (aged between 18 -45) and seventeen age-matched controls on a nonword repetition task. The nonwords varied in length and phonological complexity. The following are the words used in the study:

1- “mab” (/mæb/)
2- “mabshibe” (/mæbʃaIb/)
3- “mabfieshabe” (/mæbfaIʃeIb/)
4- “mabshaytiedoib” (/mæbʃeitaIdɔIb)

Kinematic measures of the upper and lower lip were recorded as the participants repeated the nonwords. The results of the kinematic analysis revealed that the increase of the phonological complexity heightened instability in inter-articulatory coordination in both groups of participants. The results also pointed to the idea that increasing linguistic processing demands by increasing phonological complexity negatively affected the speech motor system on both the healthy adults and the adults who stuttered.

The previously discussed results of healthy children and adults as well as children and adults who stutter support the notion that the manipulation of linguistic processing contributes adversely on the speech motor system by increasing the variability and decreasing the stability of the articulators. Similarly, studies on children diagnosed with specific language impairments have presented data showing that disfluency rates increased concurrently with an increase in length and syntactic complexity (Logan & Conture, 1997; Silverman & Bernstein Ratner, 1997; Yaruss, 1999; Zackheim & Conture, 2003).

Brumbach and Goffman's (2014) study on children with specific language impairments and healthy age-matched controls revealed that increases in syntactic complexity are associated with speech motor processing interruptions. In their study, the researchers examined sentence production in eleven children with specific language impairments (aged 4 to 6) and twelve age-matched peers. The participants produced sentences, either primed or repeated, that were matched for word length and only differed as to whether the phrase contained a particle (i.e., Tip over the block) or a preposition (i.e., Jump over the block). Kinematic measures were recorded for articulatory movement for the upper lip, lower lip, and the jaw (see Figure 1.5). Additionally, utterances were analysed for errors, articulatory duration, and articulatory variability. In both groups, sentences containing particles were considered more syntactically complex and were longer in duration. The children with specific language impairments demonstrated higher articulatory variability, an increase in errors, and poorer speech motor skills compared to the age-matched controls in the syntactically complex sentences. These results provide further evidence that linguistic complexity directly affects articulatory measures, particularly in children with impairments being affected to a higher degree.

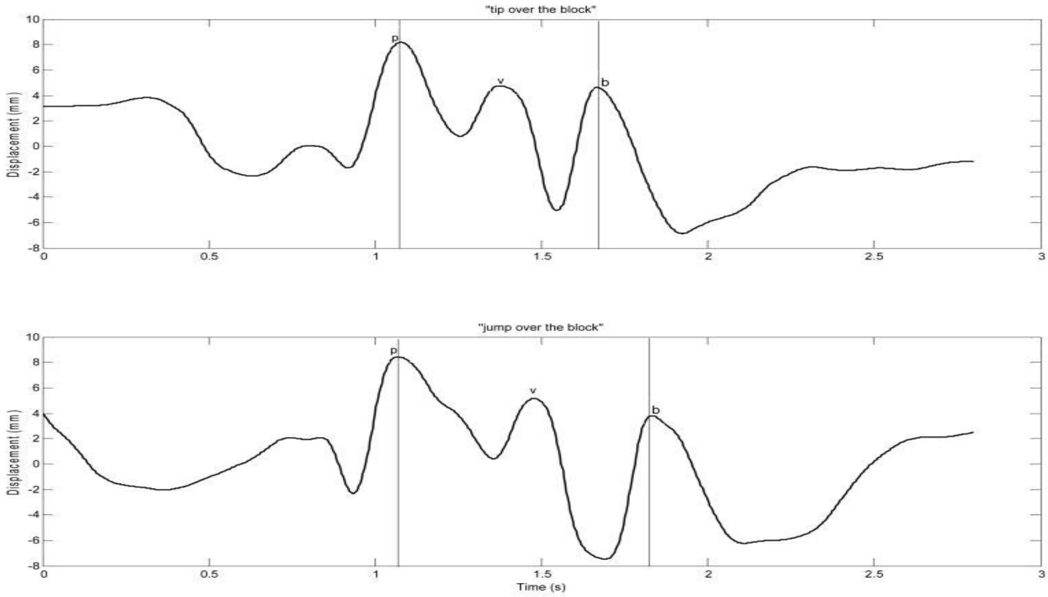


Figure 1.5 Sample of the Kinematic analyses for the phrases 'Tip over the block' and 'Jump over the block'. Downward movements correspond to lower lip opening and upward movement corresponds to lip closing (Brumbach and Goffman, 2013).

To conclude, typically developing children and children with speech motor impairments typically make articulatory simplifications (Prelock & Panagos, 1989) while showing increased articulatory error production (Kamhi, Catts, & Davis, 1984) and increased speech motor variability when linguistic variables are manipulated, such as syntactic and phonological complexity (Maner et al., 2000). Furthermore, children who stutter demonstrate higher disfluency rates in sentences considered syntactically complex as compared to healthy age-matched controls (Logan & Conture, 1997; Ratner & Sih, 1987; Silverman & Bernstein Ratner, 1997; Yaruss, 1999; Zackheim & Conture, 2003).

Comparably, healthy and speech-impaired adults displayed similar results to healthy and speech-impaired children in the interaction between linguistic and speech motor processes. Increased syntactic complexity and utterance length have been associated with increased error rates, changes in lower lip EMG amplitude, and increased variability in the articulatory movements of speech-impaired adults and healthy controls (Kleinow & Smith, 2006). Thus, manipulations of linguistic variables directly impact speech motor variability in both children and adults in equal measure.

Similar to the results discussed above, the interaction between utterance length and syntactic complexity and its effect on speech motor control has also been observed in adults. Strand and McNeil (1996) examined the effects of utterance length and syntactic complexity on people with apraxia and age-matched controls. The participants were asked to repeat single words (i.e., “cook”), word-strings (i.e., “cook-cook-cook”), and sentences (i.e., “I cook stew slowly on a pot”) where the stimuli was constructed with one of the following vowel contexts, /u/ and /ei/, and the diphthong was considered more complex than a single vowel. The researchers reported that the participants with apraxia exhibited significantly longer vowel durations and between word duration in both the word-strings and sentences when the diphthong /ei/ was embedded in the word/sentence than control speakers. The results of this study provide further evidence that the manipulation of linguistic variables in targeted stimuli instigates changes in temporal measures for the execution of speech, as the impaired participants with apraxia were more significantly affected by the experimental manipulations.

The interaction between linguistic and speech motor performance was furthermore measured in a study by Walsh and Smith (2011) on sixteen people with Parkinson’s disease and sixteen healthy age-matched adults. The participants were asked to repeat six sentences (predominantly containing bilabial consonants) that varied in length and syntactic complexity. Complexity was manipulated so that sentences containing declaratives were considered simple and sentences containing a subject-relative clause, or an object-relative clause were complex. Kinematic measures of upper lip, lower lip, and jaw were recorded during the sentence repetition. Increases in utterance length and syntactic complexity negatively affected both the participants with Parkinson’s and the healthy adults in reaction time analysis, accuracy, articulatory variability, and articulatory coordination. However, the participants with Parkinson’s exhibited longer reaction times, higher error rates, and higher articulatory discoordination and variability than the healthy controls.

Thus, from the studies mentioned above, one may infer that increasing speech demands, such as an increase in linguistic complexity, will directly influence speech motor control, variability, and coordination. In specific populations with speech motor impairments such as SLI, stuttering, Parkinson’s disease, and aphasia, an increase in linguistic loading leads to measurable changes in muscle activity and articulation. Empirical evidence demonstrating the interaction of lexical and speech motor processes in people with aphasia will be discussed in the upcoming section 1.1.4.

1.1.4 Interaction of Linguistic and Speech Motor Processes in People with Aphasia

Speech production deficits and speech errors in people with aphasia have been studied extensively and research has provided evidence for the possible interaction between linguistic and speech motor processes in word production.

1.1.4.1 Behavioural studies measuring the interaction in people with aphasia.

The speech production of people with aphasia has also been investigated through the analysis of voice-onset time (VOT). In general, people with non-fluent aphasia have been found to have more variable VOT's than people with fluent aphasia (Baum, Blumstein, Naeser, & Palumbo, 1990; R. Kent & McNeil, 1987; Wambaugh, West, & Doyle, 1997).

Kurowski and Blumstein (2016) tested seven individuals with aphasia, all with a diagnosis of either Broca's, Conduction, or Wernicke's aphasia. The participants were asked to produce syllable-initial voiced and voiceless fricative consonants 'z' and 's' in consonant vowel syllables (e.g., zoo, sing) followed by one of five vowels (a,e,i,o,u) in two conditions (isolation and carrier phrase). Acoustic analyses measuring duration and amplitude properties of the fricative consonants were conducted. Findings of the study revealed that for all the participants, regardless of the diagnosis, phonemic errors left an acoustic trace which instigated an error in the production. The acoustic trace of the fricative consonant suggests that there is in fact a co-activation of the lexical representation in the selection of the targeted word which influenced articulatory processes. These results challenge the belief that speech production is serial and discrete, rather suggesting that speech errors such as phonemic paraphasia reflect the co-activation between phonetic properties and articulatory implementation.

Nespoulous et al. (2013) measured voicing control on four people with Broca's aphasia during the production of target words that included 345 targeted consonants. For each of the targeted consonants being produced, perceptual and acoustic analyses were conducted to determine the nature of their deficits: phonological (pre-motor level speech processing) or phonetic (motor level). Measurements included were total sound duration, number of release bursts, degree of glottal closure during occlusion or constriction (Voice Termination Time) and supra-glottal (Formant Termination Time, defined as the time between the end of the preceding vowel and the end of the prolongation of formants' energy in the obstruction phase). Their results concluded that all the participants had well-preserved phonological voicing but a low-level motor deficit that affected the way they handled timing and the coordination of the glottal and supra-glottal articulators (the coordination of the activation of the glottal excitation as well as supra-glottal closure).

Bose et al. (2007) investigated the effects of the manipulation of lexical variables (word and bigram frequency) on lexical access (reaction times) and motor preparation (word duration) on eight people with aphasia and ten healthy controls. The participants in this study repeated single mono-syllabic words in two different levels of frequency distribution. Firstly, word frequency, which is related to whole words (high or low) and secondly, bigram frequency which refers to “the frequency in which particular pairs of letters occur in a specified position of a word of given length”. The results of this study were indicative of how the manipulation of lexical properties of a single word can influence speech motor properties. Both word and bigram frequency significantly influenced the speech motor performance for both participant groups displaying longer word durations for the high frequency items. The significant effect of word and bigram frequency on word durations demonstrates the direct influence of linguistic characteristics on the articulatory mechanisms in word production.

Bose et al. ’s (2011) case study measures the interaction of linguistic and articulatory processes by examining the manipulation of semantic processing production complexity in word reading. The participant, JO, was a fifty-two-year-old woman with non-fluent aphasia and dyslexia. The participant was required to read 300 common monosyllabic and multi-syllabic words that were divided into 20 semantic categories (homogenous vs heterogeneous with 15 words in each category) and varied in articulatory complexity (simple vs complex). JO produced an increased number of errors in the words that were considered phonetically complex and were in the semantically blocked condition. These results are indicative of a strong interaction between linguistic and articulatory processes where the phonetic complexity and semantic context of the words read directly affected reading accuracy.

Ultimately, behavioural studies such as the ones mentioned above have demonstrated that linguistic characteristics of verbal stimuli directly influence speech output in people with aphasia. For instance, as the argument structure of a verb increases in complexity (i.e., as the number of arguments associated with the verb increases), people with non-fluent aphasia have greater difficulty producing the verb in isolation as well as in sentences despite their intact knowledge of different argument structures (Bastiaanse & Edwards, 2004; De Bleser & Kauschke, 2003; Kim & Thompson, 2000; Luzzatti et al., 2002). Similar results have been reported on accuracy and reaction time in people with aphasia, where participants were faster to name words with many phonological neighbours and less likely to make errors (Goldrick, Folk, & Rapp, 2010; Gordon, 2002). Moreover, participants showed shorter gaze duration and higher accuracy in naming when it came to words with a high name agreement (Lee, Yoshida, & Thompson, 2015).

To conclude, in aphasia, irrespective of type and severity, linguistic deficits are apparent. However, minimal studies have to my knowledge measured the effect linguistic variations on speech motor functions in people with aphasia.

1.1.4.2 Kinematic and acoustic studies measuring the interaction in people with aphasia. Providing an accurate account of the speech motor control capabilities of people with aphasia during speech production has been an imperative goal in neurolinguistic research. Hence, several studies have been conducted with the aim of investigating articulatory timing and coordination in speech production on people with aphasia (Bose & van Lieshout, 2008, 2012; M. R. McNeil & Kent, 1990; Sasanuma et al., 1987).

Bose and van Lieshout (2012) explored the kinematic parameters and lip coordination in five people with aphasia and five age- and gender-matched healthy adults. The participants in the study performed speech-like (monosyllable /pa/) and non-speech (opening and closing of lips) tasks in familiar and unfamiliar (clenched teeth) conditions while increasing motor demands by increasing the rate of utterance production (normal and fast). Upper and lower lip movements were characterised using kinematic parameters and multi-articulator coordination parameters (peak velocity, amplitude, duration, and cyclic patio-temporal index, movement cycle variability). Their results indicated that the individuals with aphasia showed lesser amplitudes and increased movement durations for upper lip, high patio-temporal variability for both lips and higher variability in lip coordination as compared to the healthy controls.

Additionally, Bose and van Lieshout (2008), measured the influence of utterance length and rate on speech movement kinematics in five people with aphasia and five age- and gender-matched adults. The researchers compared the lip and tongue movements of the participants in tasks where the linguistic characteristics of the stimuli were varied by increasing the number of syllables and articulation was varied by the manipulation of speech rate. Upper and lower lip movement data were collected for mono-, bi-, and tri-syllabic non-word sequences. Their findings indicated that increasing syllable length had a significant effect on speech movement execution with peak velocity, amplitude, and duration exhibiting a significant increase in their values when increasing from the mono- to bi-syllabic conditions. The effect of speech rate on lip kinematics was also evident: there was a decrease in movement and duration in fast rates as compared to slower rates. These findings provide evidence that linguistic characteristics of utterances do in fact influence speech motor movements, consequently verifying the clear relationship between linguistic and speech motor processes.

From the accumulation of evidence produced by the studies mentioned above, it is clear that speech motor skills are compromised in people with aphasia. However, these studies are restricted in specifying the nature of this compromise. Data from neurological, behavioural, kinematic, and acoustic studies on people with aphasia has verified that both people with fluent and non-fluent aphasia display speech motor control deficits. Moreover, there is evidence that linguistic features (i.e., number of syllables, length of utterance, verb and noun complexity) have a direct effect on the speech output in people with aphasia.

Therefore, from the studies cited above, one can conclude that the interaction between linguistic and speech motor processes does in fact have an effect on speech production in healthy and impaired populations. Unfortunately, there is no clear theoretical framework for word production, specifically naming models, that includes this interaction. The previously discussed empirical studies do, however, illustrate significant effects of linguistic features on speech performance and articulatory features on linguistic processing (Smith & Goffman, 2004). Those considerations point to a complex interplay of linguistic and speech motor processes in the production of single words and are important for the future development of theoretical models and the understanding of language processing in healthy and impaired individuals. In particular, they suggest the need to modify current models of speech production to incorporate both linguistic and speech motor control parameters. Consequently, this study will be utilising a picture naming task with manipulations to both the articulatory complexity and semantic contexts during lexical access to measure the interaction of linguistic and speech motor processes on people with aphasia and healthy older adults.

1.1.4.3 Functional neurological interactions of language and motor areas of the brain in people with aphasia. Considerable evidence from neuroscience research has indicated that the language areas of the brain are functionally interconnected with motor areas (D'Ausilio et al., 2009; Hickok, 2009; Meister, Wilson, Deblieck, Wu, & Iacoboni, 2007). A strong association between the activation of motor areas of the brain during linguistic processing has been consistently reported, indicating that the two systems have shared functional neural resources (de Lafuente & Romo, 2004; Hauk et al., 2004). Numerous studies in neuroscience and neuropsychology on people with aphasia have demonstrated functional links between sensorimotor brain structures and the language cortex, utilising magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation (TMS).

TMS is a non-invasive procedure that uses magnetic fields to stimulate nerve cells in selected areas of the brain. The use of electrical stimulation on the motor cortex via TMS has yielded remarkable results for people with aphasia in regaining lost language functions (Dammekens, Vanneste, Ost, & De Ridder, 2014). The pre-activation of the motor areas while individuals with aphasia performed a picture-naming task resulted in improved lexical retrieval as measured by reaction times and accuracy (Meinzer, Breitenstein, et al., 2011; Meinzer, Harnish, Conway, & Crosson, 2011). Hamilton et al. (2010), conducted a study using TMS on a patient with non-fluent aphasia for a total of six sessions. The TMS was administered to six separate sites in the motor cortex, specifically in Brodmann Areas. Their results indicated that stimulation to Brodmann areas 44 and 45 (Broca's area) was correlated with a significant increase in naming performance. After concluding the six sessions of TMS, a generalisation to non-treated items exhibited significant improvements in picture description and fluency in that patient.

Additionally, a recent meta-analysis that included seven studies of a total of 160 individuals with aphasia was conducted to examine the effectiveness of using TMS targeting Broca's area as a treatment method for language recovery post-stroke (Ren et al., 2014). The results of the meta-analysis indicated a clinically positive effect of TMS for people with aphasia, with enhanced overall language function, expressive language, naming, repetition, writing, and comprehension. Converging evidence has also suggested that people with aphasia do indeed exhibit a significant improvement in lexical-retrieval (Baker, Rorden, &

Fridriksson, 2010; Fiori et al., 2013; Fridriksson, Richardson, Baker, & Rorden, 2011; Marangolo et al., 2014), fluency of speech (Marangolo, 2013; Marangolo et al., 2014), and oral production (Marangolo et al., 2011) when speech and language treatment is combined with TMS and activation of both linguistic and motor circuits is achieved.

In conclusion, it is evident from studies on both healthy and impaired children that a significant link between speech motor and lexical processes exists. However, what is still not well-established is the relationship between executive control functions on linguistic and speech motor processes. At the same time, there is a growing number of research studies indicating a relationship between linguistic and executive control processes. Therefore, the aim of this study is to measure the interaction of all three processes – linguistic, speech motor, and executive control – in order to shed light on the possible associations of all three processes on effective word production.

1.1.5 Executive Control Functions and Their Influence on Lexical Access

Executive functioning has been defined in many different ways. Indeed, researchers have debated how to establish a common understanding of the construct of executive function. In the fields of Cognitive Psychology and Neuropsychology, various models of executive functioning have been developed to further understand the construct of executive function and working memory, and their relation to verbal memory performance (Bailey, Dunlosky, & Kane, 2011; Barch & Sheffield, 2014; Hedden & Yoon, 2006; Lezak, Howieson, Bigler, & Tranel, 2012; McCabe, Robertson, & Smith, 2005; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). Some groups have focused on differentiating between different domains of executive functioning (Anderson, 2002; Miyake et al., 2000), while others have focused on redefining or identifying latent constructs that are common in working memory and executive functions (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). The latter model, developed by McCabe and colleagues (2010), showed that, within an adult lifespan population, working memory capacity and executive function share a large amount of variance and can be combined into a construct the authors call "executive attention." This construct of executive attention has been shown to predict memory performance just as well as either working memory capacity or executive functioning alone (McCabe et al., 2010). Executive attention has also been validated in a study examining a sample of older adults with no psychiatric or cognitive impairment (Samarina, 2014). Our conceptualization of the term executive attention is similar to that of Miyake colleagues (Miyake et al. (2000).

Word production requires the selection of a single targeted word among a set of similar and related alternatives. The activation of the semantically related alternatives creates additional difficulty in the word selection process. For instance, if a targeted word is “dog”, alternatives that cause difficulty in the selection process would be the activation of words that describe the targeted word (e.g., mammal, animal, four-legged) or words that refer to similar items (e.g., wolf, fox, lion). The difficulty that is created by the activation of the semantically related alternatives is displayed by slower response times and lower accuracy (Roelofs, 2012; Schnur, Schwartz, Brecher, & Hodgson, 2006; Shao et al., 2015). Several research studies have proposed that successful word retrieval involves the inhibition of the activated semantically related alternatives.

A crucial component of word production is lexical access which is directed by executive control processes. According to Miyake et al. (2000), executive control processes are specific cognitive processes which control and co-ordinate the performance of complex cognitive tasks such as lexical access in word production. Miyake and colleagues have also proposed that the executive control processes that are indispensable for word production include updating, switching, and inhibition (Miyake et al., 2000; Miyake & Friedman, 2012). In the present study, I adopt the executive function framework presented by Miyake et al. (2000) and focus on the three components of executive functions mentioned above: (a) the inhibition of automatic or prepotent responses, (b) updating and monitoring of working memory representations, and (c) switching between tasks or mental sets. This framework proposes that the three executive control components were clearly separable but related in that they shared a common executive functioning factor: the ability to actively maintain task-related goals while controlling the lower-level processing using the task-related information (Miyake & Freidman, 2012). In other words, there is both unity and diversity of these sub-domains of executive control. Figure 1.6 illustrates Miyake & Freidman’s (2012) view where individual components of executive control (Figure 1.6 a) are unified by the fact that they are correlated with each other but are still separable. Figure 1.6 b depicts the loading of all the executive function tasks into a common executive function factor and additional sub-units for updating of working memory and shifting.

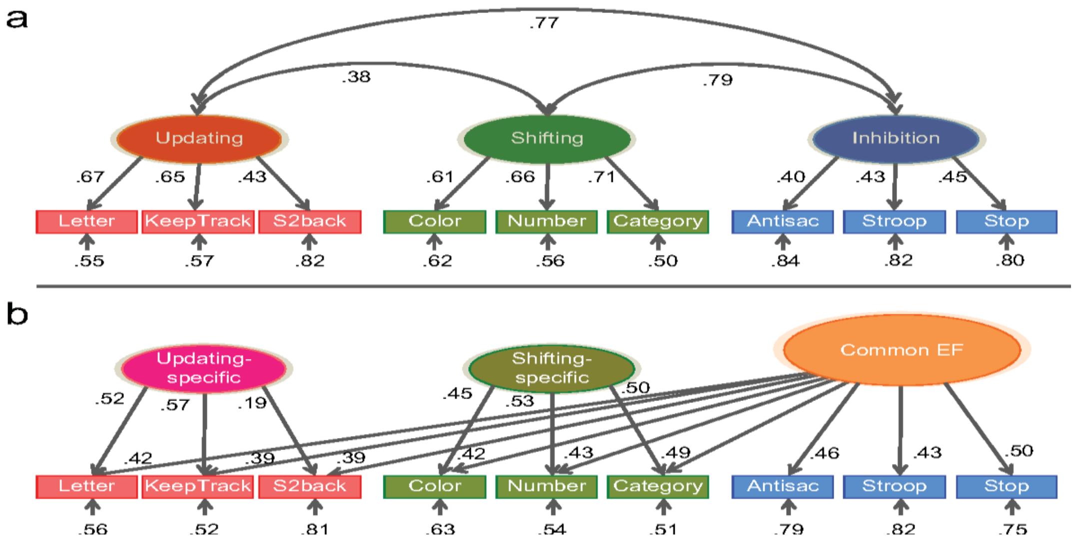


Figure 1.6 Illustrating two ways of representing executive function (Miyake and Friedman, 2012) (a) Individual components of executive functions, separable from each other. (b) Common executive function variable with additional updating and shifting sub-components.

While this view explains the different components of executive functions and their interdependencies on one another, there exists external factors such as linguistic and speech motor variables which impact the performance of the executive functioning abilities. Consequently, many recent studies have examined the interplay between linguistic processes and the components of executive functions (Belke, 2008; Crowther & Martin, 2014; Shoa et al., 2015). However, no study has attempted to measure the possible relationship between speech motor processes and executive functioning abilities. Similarly, studies from clinical populations have demonstrated that intercorrelations between many executive control tasks are typically small to moderate (Friedman & Miyake, 2017; Miyake, Emerson, & Friedman, 2000). Despite these moderate associations, throughout the literature, executive control abilities are measured using separate tasks that tap into each of these sub-domains.

Specifically, this is what we measured: inhibitory control (ability to inhibit the automatic, dominant, or prepotent responses when required), mental set-shifting (ability to shift between different tasks, rules, or mental representations), and working memory (constant updating and manipulation of relevant incoming information while replacing old irrelevant information).

1.1.5.1 Inhibition. The first and main executive function examined in this thesis concerns one's ability to intentionally suppress dominant, automatic, or prepotent responses when necessary (also referred to as inhibition). There are two primary types of inhibition, of which only one is relevant for this study (Friedman & Miyake, 2004). The first type is resistance to proactive interference, which is the ability to inhibit memory intrusions from a previous task and is not a focus of the current thesis. The second is prepotent inhibition which refers to one's ability to purposely or deliberately suppress information or distractors that are not relevant to completing the targeted task. For example, in the children's book, *Where's Waldo,* the child must ignore all of the extra visual information when searching for Waldo. Another example of inhibition would be driving the car on the weekend and suddenly finding oneself in the parking lot of one's workplace rather than at the intended destination. For the remainder of this thesis, the term inhibition will refer to prepotent inhibition.

There are countless tests that can be used to measure inhibition such as the Flanker, Simon, Antisaccade, and Stroop tasks. In psycholinguistic research, a commonly used measure to tap into inhibition is the Stroop task (Stroop, 1935). This is also the task that was chosen to measure inhibition for this research project. This task requires the participant to deliberately stop a response that is considered automatic. The participants are required to inhibit the tendency or need to read the word which is considered an automatic behaviour and to name the colour of the font that the word is written in.

Inhibition is considered essential for successful word retrieval. During lexical access for word production it is vital to inhibit non-target lexical representations in order to resolve competition, and thus produce the appropriate targeted word for production. There is evidence that suggests that poor inhibitory control is highly associated with poor performance on different language tasks, such as picture naming using the semantic blocking paradigm where lexical competition is high, and in tasks where naming of low name agreement items is required (Dromey and Benson, 2003; Kello, Plaut, and MacWhinney, 2000).

1.1.5.2 Updating of working memory. The next executive control component focused on in this research is the updating of working memory (updating hereafter). Working memory is a memory with limited capacity that is responsible for temporarily holding information for linguistic and perceptual processing. It can be readily manipulated when needed (Baddeley, 2003; Smith & Jonides, 1997).

The updating of working memory requires the frequent monitoring and updating of incoming information in order to adapt to the task at hand, then replacing or revising the items that are no longer needed with newer, more relevant information (Morris & Jones, 1990). Therefore, the items in the working memory are in need of constant updating to cope with the ever-changing environment of everyday life. For example, recalling the steps of a recipe while cooking. As proven in the example above, in order to have effective cognitive functioning, one must constantly update the internal representations of the external information as environmental information is continuously changing. As such, working memory is the cognitive skill of actively manipulating and updating relevant information, rather than the storage of the information.

In psycholinguistic research, updating ability is frequently assessed using the n-back tasks, forward and backward digit span, and the Weschler memory scale. All three of the tasks mentioned above require the constant monitoring and updating of information in the working memory, although the nature of the information that is being processed and updated varies from one task to the next. A common measure used to tap into updating ability is the backward digit span, where the participant is asked to recall the number sequence in reverse order (e.g., trial: 4 0 2 1 4 and the answer: 4 1 2 0 4). The participant's span, which is the longest number of digits that can be accurately recalled, is taken as the measure of the participants' updating of working memory (Baddeley, 2003).

1.1.5.3 Task switching. The third and final component of executive function this thesis will focus on is task switching. This is also known as the shifting of mental sets and it refers to one's ability to consciously shift attention between multiple cognitive tasks (Monsell, 1996). The ability also allows a person to rapidly and efficiently adapt to different situations. Task switching is used in everyday life and is necessary when a person is completing multiple tasks. For example, when a student is listening to a lecture and simultaneously writing up the important notes. A failure to switch properly might lead to the omission of important information or otherwise incorrect notes being written down.

Task switching has been applied and studied often in psycholinguistic research and can be tested experimentally using tasks like the Wisconsin Card Sorting Test, Trail Making Test, and the Plus Minus Task. All of the tasks mentioned above require the participant to coordinate two or more concurrent tasks. To be exact, those tasks require that several cognitive operations be coordinated simultaneously while switching between mental sets. Experiments of task switching typically consist of two simple tasks to be completed. In the first task the participants are asked to respond to stimuli that is presented without any switching present (e.g., Are the items presented the same shape? Yes/no). In the second task the participants are asked to respond by shifting/switching between two stimuli sets (e.g., Are the items presented the same shape? Yes/no and are the items presented the same colour? Yes/No). The participant's performance on these tasks is disrupted when switching from one task to another. This disruption is generally exhibited in the substantially slower reaction times and the increase in errors on the switch trials than on the non-switch trials (Monsell, 1996). Tests measuring task switching produce a measure of switch cost. The difference in accuracy and reaction times between the non-switch trials and the switch trials is known as the switch costs (Monsell, 1996). As mentioned above, the reaction times and accuracy is often poorer on the switch trials relative to the non-switch trials, calculated using the switch costs.

A detailed discussion of studies that provide evidence for the theory that executive control deficits contribute to the impaired word production in healthy and impaired adults and children will be reviewed in detail in the upcoming section 1.1.5.4 (Biegler, Crowther, & Martin, 2008; A. C. Hamilton & Martin, 2005; Kuzmina & Weekes, 2017; Novick, Kan, Trueswell, & Thompson-Schill, 2009).

1.1.5.4 Interaction of executive functions and linguistic processing in healthy adults. Numerous research studies have proposed that the specific components of executive control mentioned above (switching, updating, and inhibition) are in fact associated with linguistic aspects and word production functions (Shao et al., 2015). The influence of these executive functions is exhibited when speakers attempt to name pictures while the names of other semantically related items are activated as competitors in the lexical access, thus requiring the activation of cognitive control mechanisms so that the correct name can be selected from among the activated competitors. Other evidence has suggested that cognitive control mechanisms are in fact involved in word selection processes, with inhibition often argued to play the most important role (de Zubicaray, Wilson, McMahon, & Muthiah, 2001; Ren et al., 2014; Shao et al., 2015).

Belke (2008) tested 20 healthy undergraduate monolingual speakers on a blocked cyclic naming task whilst manipulating the working memory load by having the participants remember a string of digits, compare it to another string of digits, and finally state whether the strings contained the same numbers or not. Their findings reported a significant blocking effect, that is, the participants were slower to name items in the homogenous condition as compared to the heterogeneous condition. That blocking effect was exaggerated when the participants were asked to perform the working memory task as well as the naming task. This study demonstrates that an increased load on the working memory reduces the efficiency of the executive control mechanisms, leading to a significant increase in the blocking effect.

In a study by Shao, Janse, Visser, and Meyer (2014), the relationship between executive control and lexical access was examined using tasks that tap into inhibition (stop-signal tasks), updating (operation span) and lexical access during picture naming on 82 healthy adults. Their results indicated that lexical retrieval speed predicted the number of words named in both verbal fluency tasks and the performance speed in the stop signal task. Similar results were found in an earlier study by Shao, Roelofs, and Meyer (2012) where the influence of executive control abilities on lexical access was measured on 28 healthy younger adults. The researchers assessed executive control using the operation span to measure updating, task-switching to measure shifting, and the stop-signal tasks to measure inhibition, while lexical access was measured using a speeded timed picture naming task. Their results indicated a significant positive correlation between the stop-signal reaction times (measuring inhibitory ability) and the reaction times in the picture naming task. Additionally, their results indicated that reaction times in the picture naming task were correlated with the reaction times in the operation span task (measuring updating ability). These results are suggestive that the executive control abilities, specifically updating and inhibition, have a direct influence on lexical access. Shao et al. (2015) measured the contribution of inhibitory control on the resolution of the activated competitors during picture naming. Inhibitory control was assessed through the use of both the Stroop and the stop-signal tasks, while the sematic blocked cyclical naming paradigm was used to assess lexical access. Their results indicated that the participants which exhibited poorer inhibitory abilities in the Stroop and stop-signal tasks displayed larger semantic interference effects in the picture naming task.

To conclude, it is evident that lexical access, specifically the semantic interference occurring during picture naming, is significantly correlated to executive control abilities – especially the updating of working memory and inhibitory control (Belke, 2008; Crowther & Martin, 2014; Shao et al., 2015). Similar results were found in studies researching the influence of executive control functions on linguistic processes in individuals with aphasia (see section 1.1.5.5 below).

1.1.5.5 Interaction of executive control functions and linguistic processing in people with aphasia. Current and previous research has shown that impairments in executive control abilities, specifically inhibitory control, contributes to the linguistic deficits in people with aphasia (Des Roches et al., 2016; Hula & McNeil, 2008; Kuzmina & Weekes, 2017; Murray, 2012). The studies mentioned above as well as previous older studies have focused on the effects of the inhibitory deficits on language comprehension (Lim, McNeil, Doyle, Hula, & Dickey, 2012; M. McNeil et al., 2010) and linguistic processing in people with aphasia (Hula & McNeil, 2008; Murray, 2000; Murray, Holland, & Beeson, 1997; Tseng, McNeil, & Milenkovic, 1993). All these studies reported significantly slower and less accurate target responses in the presence of interference in the individuals with aphasia as compared to the healthy age-matched controls. These studies hypothesized that the inhibitory control abilities were inadequate in the individuals with aphasia, which then manifested itself in a decreased availability of resources for the management of the interference caused and for the inhibition of the activated distractors.

Lim et al. (2012) measured the effects of interference on the inhibitory abilities of ten individuals with aphasia and 20 age-matched healthy adults in a picture word interference task. The stimuli for the task consisted of 10 high frequency words that were matched with pictures from two semantic categories (animal and non-animal). The picture word interference task consisted of three conditions: neutral, congruent, and incongruent. In the neutral condition, only words were displayed and in the congruent condition, each picture appeared with its corresponding name at the bottom of the picture. Finally, in the incongruent condition, the pictures were paired with words from different categories. The participants were asked to indicate whether the string of letters that appeared on the screen was “animal” or “non-animal” by simply pressing the targeted key on the keyboard while reaction times and error rates were simultaneously recorded. Lim and colleagues reported a correlation between interference and an increase in error rates and reaction times in the incongruent condition, indicating inhibitory deficits. These findings support the growing body of evidence identifying the impairments in executive control as a source or a consequence of the linguistic deficits in people with aphasia.

Several studies on individuals with aphasia have indicated that the potential inability to inhibit irrelevant information activated during lexical access is the primary source of the lexical retrieval impairments in aphasia. To illustrate, Wiener, Tabor Connor, and Obler (2004) examined the influence of lexical-semantic interference and auditory comprehension on five individuals with Wernicke's aphasia and 12 age- and education-matched healthy controls using a numeric non-verbal Stroop task, with a manual response to measure interference and the Token test to measure auditory comprehension. Compared to healthy controls, the participants with aphasia demonstrated a larger interference effect with an increase in error rates and increased reaction times in the Stroop Task (similar to Lim et al., 2012). Additionally, results indicated a significant positive correlation between Stroop interference and the severity of auditory comprehension deficits.

Research has indicated that linguistic deficits are indeed a prominent issue in people with aphasia, as is the impairment of executive control. Having said this, minimal studies have measured the direct correlation of executive control processes to linguistic processes in people with aphasia. In a 2017 study, Kuzmina and Weekes explored the association between inhibition and word production, using the verbal Stroop task to measure inhibition and picture naming to measure lexical access on people with aphasia. The researchers reported a significant association between verbal Stroop and the participant's accuracy in the picture naming ability—with higher naming accuracy associated with smaller Stroop interference. This is supported by many other studies on healthy and disordered individuals that demonstrated poor performance in semantic picture naming tasks with exaggerated interference effects on some cognitive tasks, such as memory and the Stroop tasks (Freedman, Martin, & Biegler, 2004; A. C. Hamilton & Martin, 2005).

In summary, based on the existing body of literature discussed above, it appears that executive control abilities, especially inhibitory control and working memory, directly influence linguistic processes, specifically lexical access, through the reduction of the semantic interference that occurs during picture naming tasks in both healthy and impaired adults. Previous literature indicated that individuals with aphasia have impairments in linguistic, speech motor control, and executive control; however, at present there is no study that systematically measures the influence of all three processes on one another in healthy individuals and people with aphasia.

To further understand the role and potential influence of linguistic processing, speech motor control, and executive control in word production in people with aphasia, the present study seeks to explore their interaction/influence through the use of one picture naming task in which lexical access and articulatory complexity are manipulated, and six executive control tasks tapping into inhibition, updating of working memory, and shifting.

1.1.6 Methodological Challenges for Testing People with Aphasia

Research involving people with aphasia has proven to be associated with methodological challenges. Numerous methods have been applied to measure the interaction of linguistic and speech motor processes in people with aphasia. The utilisation of acoustic testing, kinematics, fMRI, MRI, and EMG's to measure the interaction can be very demanding of the participant, both technically and physically. Participants with neurological disorders such as aphasia (even the ones with milder forms), have often indicated the feeling of fatigue and a lack of concentration during experimental conditions (Chaudhur & OBehan, 2004). Due to the above reasons, researchers have been limited in the number of participants they recruit in their studies. Researchers must therefore restrict both the number and complexity of stimuli collected for each participant. Moreover, it is often difficult to find a large number of individuals who are comparable in their clinical and behavioural characteristics due to the heterogeneity of the neurogenically disordered population. Born out of these limitations, most behavioural, acoustic, and kinematic studies in aphasia are restricted to single cases or very small groups of participants (Bartle et al., 2007; Bose & Van Lieshout, 2008; Ckarj & Robin, 2008; Van Lieshout et al., 2007).

Consequently, to mitigate the challenges mentioned above, the blocked non-cyclical naming paradigm (Belke et al., 2005) was utilised in this research to investigate the relationship/interaction between linguistic (lexical access) processes and speech motor performance. The paradigm is a feasible method which can be utilised to examine the interaction of language and articulatory processes under conditions subject not only to semantic interference by increasing or decreasing semantic competition/demands at a linguistic level, but also to control for articulatory complexity within each of the words used in the picture naming categories. The use of the same stimuli on both manipulations, lexical and articulatory, is a great advantage.

Word production for people with aphasia becomes slower or less accurate when there are numerous possible options to choose from (e.g., soda → coke, pop, fizzy drink) compared to when there are fewer competitors (e.g., guitar). This is supported by numerous studies that have investigated name agreement (Bose & Schafer, 2017; Novick et al., 2009) and semantic blocking (Belke, Meyer & Damian, 2005; Biegler et al., 2008; Schnur et al., 2006; Scott, & Wilshire, 2010). The semantic blocked naming paradigm is a paradigm that is frequently used to study the processes of lexical access and lexical retrieval whilst manipulating the context in which the target items are presented. In this paradigm, participants are asked to repeatedly name items that are either grouped by semantic category (homogenous sets, e.g. fruits-apple, banana, orange, grapes) or not grouped by semantic category (heterogenous sets, e.g. cat, apple, sofa, knife). The performance of the participants in the naming of items in the homogenous sets is then compared to the heterogenous sets. The same items that are presented in the homogenous sets are generally used to generate the heterogenous sets, as illustrated in Table 1.1.

Table 1.1: *Example of How Homogenous and Heterogeneous Sets are Constructed with Each Heterogeneous Set Containing One Item from Each Homogenous Set*

		Heterogeneous Sets			
		1	**2**	**3**	**4**
Homogenous Sets	**Fruits & Vegetables**	Apple	orange	radish	banana
	Animals	Cat	dog	mouse	horse
	Things to Wear	Belt	shirt	coat	crown
	Toys	Yoyo	tent	ball	puzzle

The implementation of the non-cyclical version of the blocked semantic naming paradigm as the preferred method in this research is substantiated by multiple objectives. In the cyclical version of the semantic blocking paradigm the stimuli lists are compiled from small sets of objects presented in a repeated sequence of cycles with each cycle typically limited to 4 to 6 stimuli items. However, the goal of this research was to measure the interaction of lexical access and articulatory complexity using the semantic blocked naming paradigm rather than solely measuring the effect of semantic blocking; therefore, the non-cyclical version of naming paradigm was applied.

The use of this non-cyclical version allows us to manipulate a number of aspects, such as the generation of longer lists with an adequate number of stimuli and varying articulatory complexity in each category. This manipulation ensures that each category has a sufficient number of stimuli and responses to efficiently and effectively measure the interaction of lexical access and articulatory complexity. In conclusion, the semantic blocked paradigm is not only less demanding than the previously discussed methods, it has also been used in speech and language literature on healthy and impaired individuals, as well as people with aphasia.

As people with aphasia naturally exhibit language impairments, it was vital to determine if the cause of poor performance on the executive function tasks was a result of reduced executive control abilities or impaired language. Therefore, the tasks chosen to measure executive control rely primarily on non-verbal visuospatial stimuli and responses rather than linguistic stimuli and verbal responses (El Hachioui et al., 2014; A. C. Hamilton & Martin, 2005; Kuzmina & Weekes, 2017; Mayer, Mitchinson, & Murray, 2017). The inclusion of both verbal and non-verbal tasks allows for the impact of language material on the task performance of people with aphasia to be established.

1.1.6.1 Central findings for people with aphasia: Blocked semantic naming paradigm. The blocked-cyclic naming paradigm has been used frequently on healthy as well as neurologically impaired individuals to investigate the changes in semantic activation and lexical competition (e.g., Belke, Meyer, & Damian, 2005; Damian, Vigiliocco, & Levelt, 2001; Schnur, Schwartz, Brecher, & Hodgson, 2006; Scott & Wilshire, 2010). Studies utilising the semantic blocked naming paradigm with healthy individuals have revealed that naming pictures in the homogenous conditions show robust effects on response times in naming, with slower responses and an increase in errors (Brown, 1981; Damian, Vigliocco, & Levelt, 2001; Damian, 2003; Kroll & Stewart, 1994; Maess, Friederici, Damian, Meyer, & Levelt, 2002; Schnur et al., 2006; Schnur et al., 2009). The longer response times and the increase in errors in the homogenous condition is often attributed to the increase in competition between the targeted word (e.g. cat) and other words in the same category (e.g. dog, fox, wolf).

Numerous studies on aphasia have reported effects that are similar to the literature on semantic blocking in healthy adults (i.e., longer RT's and lower accuracy in the homogenous condition than in the heterogenous condition). For example, in a study by Scott and Wilshire (2010), a blocked cyclical design was implemented where a single person with aphasia, J.M, was compared to nine healthy controls. The results showed that the heathy adults had a slower RT in naming pictures and also exhibited an increase in naming errors in the homogenous condition compared to the heterogenous condition. Contrastingly, the person with aphasia's performance differed from the healthy controls in that her RTs and naming accuracy were significantly affected by the semantic blocking manipulation. Her naming accuracy was poorer and reaction time was longer when pictures were semantically blocked (homogenous condition) compared to when they were not (heterogenous condition).

The results discussed above were also found in a case study on an individual with non-fluent aphasia, BM, by Wilshire and McCarthy (2002). A blocked cyclical naming paradigm was applied using both a fast presentation rate and a slow presentation rate. The rate of presentation had a significant influence on accuracy, where errors increased in the homogenous condition at the fast presentation rate as compared to the slower rate. BM performed more poorly in the semantically blocked condition than in the unblocked condition, producing more errors and showing great difficulty in selecting from highly activated competitors (as his errors were mostly substitution of the target word for a word from the same category list). Wilshire and McCarthy also performed a similar blocking experiment with BM and another participant, IG, an individual with fluent aphasia (mild anomia). The results revealed that the semantic blocking effect was only evident in BM, not in IG.

Biegler, Crowther, & Martin (2008) obtained similar results of the blocking effect in their study of three people with aphasia, two of whom had non-fluent aphasia and one with fluent aphasia, and seven healthy older adults as controls. The study reports inhibitory effects of semantic blocking on both RTs and accuracy in the participants with non-fluent aphasia, and only on RT in the participant with fluent aphasia and the healthy older adults. While the blocking effects for the healthy older controls and the participant with fluent aphasia were similar to one another, the effects of blocking on the two participants with non-fluent aphasia were exaggerated, displaying a larger difference in RT and accuracy in the homogenous categories as compared to the heterogenous categories. The results are suggestive that people with non-fluent aphasia experience much more difficulty inhibiting activated items once they have been selected. This in turn causes stronger competitors when naming items within the same semantic category, causing longer RTs and a decline in accuracy. The results reported previously were also corroborated in older studies of individuals with aphasia. In a case study on a participant with non-fluent aphasia, McCarthy & Kartsounis (2000) reported an increase in errors in the semantically blocked condition when pictures were required to be named at a fast rate. The participant's error analysis described the errors as mostly semantic errors and omissions. The error rate was not significant during the slower rate of presentation.

Using the blocked cyclic design, Schnur et al. (2006) tested 18 people with aphasia and age-matched controls. The participants were divided into subgroups, one with fluent aphasia and the other with non-fluent aphasia. General results showed that the errors in the homogenous condition were greater than in the heterogeneous condition for both groups of aphasia, but the overall blocking effect was more evident in the non-fluent aphasia group. An error type analysis was also conducted, revealing that the blocking effect led to an increase of semantic errors and omissions in the semantically related categories for both groups of people with aphasia, but the fluent people with aphasia did not show a significant semantic blocking effect in error rates. Schnur attributed the increase in the semantic blocking effect for the non-fluent patients to the over-activation of competitors in the homogenous condition.

In a recent study by Harvey, Traut, and Middleton (2018), fifteen participants with aphasia (six fluent, nine non-fluent) were asked to name 615 pictures from homogenous and heterogenous categories in order to measure the effect of semantic interference on error types. Results of their study revealed effects of semantic interference that were evident in accuracy and reaction time analysis. The participants exhibited significant semantic interference reflected in an increase in errors and longer reaction times in the homogenous conditions. Also, semantic interference was manifested specifically by an increase of semantic errors, especially in the homogenous conditions.

Considering the previously discussed scientific results, it is evident that the semantic interference effect in aphasia research is consistent. It is clear that the effect of semantic blocking is more common and significant in individuals with non-fluent aphasia, such as Broca's and Transcortical Motor. These effects emerge as semantic errors/substitutions and/or omissions during the error analysis of the naming task (Biegler et al.,2008; McCarthy& Kartsounis (2000). Studies have also reported semantic interference in individuals with fluent aphasia, such as Wernicke's and Anomic aphasia (Harvey, Traut, & Middleton; 2018). Those studies have reported an increase in RT in homogenous conditions, which supports the semantic blocked effect (Biegler et al., 2008; Schnur et al., 2006). To conclude, it is clear that many people with aphasia exhibit an effect of semantic interference, but the effect will vary according to the type and severity of aphasia.

1.1.7 Measuring Articulatory Complexity

It has been suggested that phonetic, segmental, and syllabic aspects all play an equally important role on word variables. It is therefore vital to consider both phonological and phonetics together, as well as their interaction, in order to understand and measure articulatory complexity (Chitoran & Cohen, 2009; Maddieson, 2009). Empirical evidence from studies of phonetics and phonology, measures of production complexity have been proposed, implicating both phonological (syllabic and segmental) and articulatory (phonetic) features of words. For example, empirical evidence has revealed that consonants are considered more complex than vowels (Chitoran & Cohen, 2009; Robb, Bleile, & Yee, 1999), clusters more complex than singletons (Elbert & McReynolds, 1979, Gierut, 1999; Gierut & Champion, 1999: Gierut, 2001), developmentally later acquired sounds more complex than sounds acquired early (Gierut, Morriesette, Hughes, & Rowland, 1996; MacNeilage & Davis, 1990), and higher numbers of syllables more complex than single syllables (Ablinger, Abel, & Huber, 2008).

Studies measuring articulatory or Phonetic Complexity in people with aphasia frequently adopt single measures, such as number of phonemes and the presence of clusters or a presence or a combination of phonetic different features with minimal theoretical motivation (i.e., number of clusters plus number of syllables plus number of phonemes in Nickels and Howard (2004). Two measures of phonetic complexity have been developed in child development literature: the Index of phonetic complexity (IPC, hereafter) (Jakielski, 2000) and the Word Complexity Measure (Stoel-Gammon, 2010). Both code for a number of features (phonological and articulatory) which are assigned complexity points on the basis of the lateness of acquisition of those features in typical child language development. Also, both the IPC and the Word Complexity Measure reflect features that are considered more complex in aphasia literature (i.e., presence of fricatives, presence of consonant clusters). The IPC is based on Mac Neilage and Davis' (1990) approach to speech acquisition where developmentally later acquired sounds are considered more complex than sounds that were acquired earlier. It also provides a composite metric of complexity that consists of eight sub-measures (consonant by place, consonant by manner, vowel type, singleton consonant by place, vowel by class, word shape, word length, contiguous consonants, cluster by place).

The IPC was chosen as the measure of articulatory complexity for this research as it has been implemented in a number of studies with healthy and impaired adults (Howell, Au-Yeung, Yarus Eldridge; 2006). The IPC has already been successfully employed as a metric for complexity measures in numerous paediatric and adult speech production studies. In a dysfluency study by Howell, Au-Yeung, Yarus and Eldridge (2006) it was revealed that high IPC scores on words predicted higher rates of stuttering in adults. The IPC was also applied in an adult neurological study where Bose, Colangelo, and Buchanan (2011) employed the semantic blocking paradigm using words with varying complexity. They found an interaction between production complexity and semantic blocking effects, suggestive of a significant interaction between semantic retrieval and the speech motor output.

In order to test the influence/interaction of the linguistic processes on speech motor processes in single word production, this research manipulates lexical access and articulatory attributes in terms of production complexity of the words used in the semantic non-cyclical blocked paradigm.

1.1.8 Measures of Performance: Accuracy, RT, and WD

As shown in the studies above, word production studies on people with aphasia emphasise analysing accuracy and error types. Although errors are certainly of interest in the study of speech impairments, imperative information about the process of speech planning and speech production may be overlooked when focusing exclusively on observable errors. Previous research on healthy and impaired populations has verified that speed data, such as RT and WD, should be indispensable in the assessment of the severity levels of lexical access and word production (Kello & Plaut, 2000; Kawamoto, Kello, Higareda, & Vu, 1999).

The reporting of accuracy data alone, without any discussion of speed of performance in terms of RT and WD, provides an inadequate and potentially misleading representation of the actual speech production deficit in people with aphasia (Crerar, 2004). This research will utilise temporal measures such as RT and WD, since they have a much higher sensitivity to detect potentially subtle deficits in word production and word retrieval in people with aphasia (Crerar, 2004). Those temporal measures are also able to provide a clear picture of the potential correlation between linguistic and speech motor processes in people with aphasia. In line with the previously discussed studies, RT will be used in this research as an index to measure linguistic processing, lexical access, and planning, while WD will be used as an index to measure speech motor performance in terms of the time it takes to execute the targeted linguistic units (Damian, 2003; Maas & Mailend, 2012; Rastle, Croot, Harrington, Colheart, 2005; Schwartz, 1995).

Most experiments on people with aphasia have used measures of accuracy, error types, and reaction time to investigate word production, lexical access, and word retrieval (Biegler et al., 2008; McCarthy& Kartsounis, 2000; Schnur et al., 2006). Those studies have not implemented the use of word duration as a measure for word retrieval and/or production. Nevertheless, the combination of both reaction time and word duration as temporal measures is robust in the detection of potential deficiencies in lexical access and/or word production (Biegler et al., 2008; McCarthy& Kartsounis, 2000; Schnur et al., 2006). The previous studies utilised reaction time to assess linguistic processing and motor preparation of linguistic units required to produce the targeted word. However, in this study, an addition of a WD measure will be used to assess speech motor performance (the time it takes to articulate the targeted word). Analysing RT and WD for picture-naming will provide a clear understanding about the potential interaction between lexical access and speech motor processing during word production in the speech impaired populations, such as those diagnosed with aphasia.

1. 2 Aim of Thesis

This PhD research intends to investigate some of the outstanding issues in word production literature in the context of individuals with aphasia and healthy older participants. Specifically, this dissertation aims to investigate the relationship between linguistic, speech motor, and executive control processes. The current study employs the semantically blocked non-cyclical naming task to investigate the influence of speech motor control (i.e., articulatory complexity) on linguistic processes (i.e., lexical access) and the role of executive control abilities; specifically, inhibition, updating of working memory, and task switching on word production.

This introductory review has briefly outlined previous research that has begun to establish an understanding of the complex relationship between linguistic processes and speech motor control in healthy and impaired individuals (Goldrick & Blumstein, 2006; Maner et al., 2000). A brief overview of the influence of executive control processes on linguistic processing has also been outlined. Despite this intensive work on the relationship between aspects of linguistic, speech motor control, and executive control - a fairly impressive accumulation of knowledge over the last several decades - there has been little progress in the understanding of the influence of all three variables on neurologically impaired individuals such as those with aphasia.

A number of questions still remain unanswered, and these form the basis of our research questions for the current thesis. The four experimental chapters included in this thesis will address some of the gaps we have identified in the existing literature. In Phase 1, the interaction between linguistic and speech motor processes in word production was assessed on healthy younger and healthy older adults (Chapter 2) as well as people with aphasia (Chapter 3). In Phase 2, Chapters 4 and 5, we investigate the relationship between linguistic, speech motor, and executive control processes in healthy younger and healthy older adults (Chapter 4) and in people with aphasia (Chapter 5). Table 1.2 presents a summary of all the experimental chapters with their specific research questions and the methodology.

Table 1. 2: *Summary of the Experimental Chapters with the Research Questions and Methodology*

<table>
<tr><td colspan="2">Chapter 2. Measuring the Interaction of Linguistic and Speech Motor Processes during Picture-naming in Healthy Younger and Older Adults</td></tr>
<tr><td>Specific research questions</td><td>Methodology</td></tr>
<tr><td>1- To investigate the influence of manipulations to the linguistic and speech motor processes on the performance of HOA and HYA on a picture-naming task, on the following variables:
Accuracy
Reaction time
and Word duration</td><td>Participants: Sixty healthy, right-handed, monolingual British adults (20 healthy young and 30 healthy old adults).

Task: A non-cyclical blocked naming task was implemented where participants were required to name a series of pictures in two semantic contexts: homogenous and heterogeneous. There were 10 homogenous sets and 10 heterogeneous sets with each set constructed in such a way as to have 10 exemplars, with 5 of them considered phonetically simple and the other 5 phonetically complex, based on the Index of Phonetic Complexity.

Variables: Accuracy, reaction time, word duration</td></tr>
<tr><td colspan="2">Chapter 3. Measuring the Interaction of Linguistic and Speech Motor Processes during Picture-naming in Aphasia</td></tr>
<tr><td>1- To investigate the influence of manipulations to the linguistic and speech motor processes on the performance of HOA and PWA on a picture-naming task, on the following variables:
Accuracy
Reaction time
and Word duration

2- Does the fluency of speech in PWA (fluent vs non-fluent) effect the influence of linguistic and speech motor processes?

3- Does the influence of linguistic and speech motor processes depend on the individual participant characteristics in PWA?</td><td>Participants: 17 individuals with aphasia and 17 age- and education-matched healthy adults.

Task: Same as Chapter 2.

Variables: Same as Chapter 2.</td></tr>
</table>

Chapter 4. Measuring the Interaction of Linguistic, Speech Motor, and Executive Control Processes in Word Production in Healthy Younger and Older Adults	
1- To determine the difference between the performance of executive control measures between the healthy younger and healthy older adults. 2- To determine if there is a relationship amongst the effect of semantic interference on the accuracy, RT (linguistic processes), and WD (speech motor performance) during picture naming and executive control processes (inhibition, updating, shifting) in healthy younger and older adults.	*Participants:* Same as Chapter 2. *Tasks:* The components of executive control were assessed using two individual measures for each component. The spatial and word colour Stroop were measures for inhibition, the n-back and digit span task were measures of updating, and the trail-making and the same-different tasks were measures of switching. *Variables:* Reaction times, error rates, Stroop ratio, and the d-prime were measures used for the executive function tasks and semantic interference effects on RT and WD from the picture-naming task.
Chapter 5. Measuring the Interaction of Linguistic, Speech Motor, and Executive Control Processes in Word Production in Aphasia	
1- To determine the difference between the performance of executive control measures between the people with aphasia and healthy older adults. 2- To determine if there is a relationship amongst the effect of semantic interference on the accuracy, RT (linguistic processes), and WD (speech motor performance) during picture naming and executive control processes (inhibition, updating, shifting) in people with aphasia and healthy older adults.	*Participants:* Same as Chapter 3. *Tasks:* Same as Chapter 4. *Variables:* Same as Chapter 4.

Chapter 2

Measuring the Influence of Linguistic and Speech Motor Processes during Picture Naming in Healthy Younger and Older Adults

2.1 Abstract

Background:

Word production involves integration and interaction of several linguistic and speech motor processes. However, interactions between language and speech motor functions remains underspecified. In this research, we investigate the interaction of linguistic processes (through the manipulation of semantic activation by using the non-cyclical blocked picture naming paradigm) and speech motor processes (by varying the articulatory complexity of the words) in healthy younger adults and healthy older adults.

Aim:

The aim of this research was to determine if there are differences in word production accuracy, RT, and WD when healthy younger adults and healthy older adults named pictures with varying articulatory complexity (simple vs complex) in semantically homogenous/heterogeneous conditions.

Method:

Thirty healthy older adults (Mean= 74.0, SD= 8.71) and thirty healthy younger adults (Mean= 23.0, SD= 3.98), who were matched for education, participated in the study. The investigation implemented a non-cyclical blocked naming paradigm where participants were required to name a series of 100 black and white pictures depicting nouns in two semantic contexts: homogenous and heterogeneous. There were 10 homogenous sets and 10 heterogeneous sets. Each set has 10 exemplars, of which five were phonetically simple and five were phonetically complex based on the Index of Phonetic Complexity. Variables measured were accuracy, RT which measured the linguistic processing until motor preparation, and WD measured speech motor production.

Results:

As expected, compared to healthy younger adults, the healthy older adults produced words with decreased accuracy, increased RT and increased WD. Semantic blocking variation resulted in predicted increase in RT as well as increased WD in homogeneous condition. Articulatory complexity variation also resulted in increased RT and increased WD for complex words. Articulatory complexity also demonstrated an interaction with Group, such that, compared to healthy younger adults, the healthy older adults showed significantly longer

RT for complex words. There were no interactions between semantic blocking and articulatory complexity, nor any three-way interactions with the Group.

Conclusions & Implications:

Findings revealed that indeed the healthy ageing processes has a direct influence on naming accuracy, lexical access, and speech motor processes. Importantly the findings also indicate that semantic blocking influences actual articulation time of the words as indicated by increased WD in homogeneous conditions. This finding challenge theoretical assumptions that semantic interference is restricted to the lexical-semantic level of word production with indications that the interference extends beyond the linguistic levels and cascade to the speech motor performances. The lack of interactions of semantic blocking and articulatory complexity for the variables are discussed within the framework of the type of blocking task chosen for this study, participant characteristics and sensitivity of measures.

2.2 Introduction

Considerable research in spoken word production has focused on the study of speech and language separately and independently. Speech production in healthy and impaired individuals has been studied predominantly using two different approaches: a psycholinguistic approach that focuses on the levels of semantics, phonemes, and linguistic units of speech production, and a speech motor control approach that focuses on kinematic forces, movement trajectories, and feedback control. Despite their mutual interest in understanding spoken word production, there are minimal interactions between these two approaches as they focus on entirely different levels of speech production. While the psycholinguistic approach is concerned with a more abstract, higher level of linguistic processing, the motor control approach is concerned with lower level articulatory control processes (Levelt et al., 1999; Van der Merwe, 1997).

Previous research has examined how demands on linguistic processing may influence the actual physical production of speech (articulation). Those studies have confirmed that speech motor control can be compromised when linguistic processing demands increase (MacPherson & Smith, 2014; Yaruss, 1999). For example, a study of labial kinematics on individuals who stutter revealed that the participant's speech became more variable in its execution when the utterance produced was considered linguistically challenging (Kleinow & Smith, 2006); Ballard et al., 2001). Likewise, in a study by Maner et al. (2000), it was confirmed that increased utterance length and syntactic complexity resulted in an increase of the spatiotemporal variability of the lips during phase repetition.

With reference to ageing, the nature of the underlying senescence has been customarily associated with an expected decline of cognitive, motor, and sensory functions, accompanied by brain atrophy and neural loss (Park, 2002; Reuter-Lorenz & Lustig, 2005; Salthouse, 1996, 2009). Correspondingly, advanced ageing is additionally associated with a decline in the planning of movements, manifested in longer reaction times in a variation of motor tasks (Cerella, 1985; Jordan & Rabbitt, 1977; Niermeyer, Suchy, & Ziemnik, 2017) and longer movement durations (Aoki & Fukuoka, 2010). Despite the significance of spoken language production to everyday communication, little is known about the manner and extent of the interaction between motor aspects of speech production, linguistic processing, and ageing. Therefore, this study will investigate the influence of linguistic and speech motor processes on healthy ageing.

2.2.1 The Effect of Ageing and Linguistic Processing Decline

Spoken word production is an incredible skill that allows the speaker to access his/her mental lexicon of 100,000 words and speak at a normal rate of 2 to 4 words per second (Levelt, 2001; Robb, Maclagan, & Chen, 2004). Furthermore, research has confirmed that errors in spoken word production occur approximately once or twice for every 1000 words (Levelt, 2001), with older adults experiencing more errors and word-finding difficulties than younger speakers (Burke & Shafto, 2004; Kemper, 2006; Thornton & Light, 2006).

Countless research studies have been conducted over the past 35 years in an effort to examine the effect of normal ageing on naming ability – with controversial conclusions. Several studies recorded results which indicated a significant difference in accuracies and reaction times in the naming of items between healthy younger and healthy older adults (Connor, Spiro III, Obler, & Albert, 2004; Feyereisen, 1997; Goulet, Ska, & Kahn, 1994; Schmitter-Edgecombe, Vesneski, & Jones, 2000). Conflicting results from other studies indicated no age-related deficits in picture-naming, as healthy older and healthy younger adults performed with comparable accuracies and reaction times (Béland & Lecours, 1990; Farmer, 1990). The discrepancies in the findings on the age-related change in picture-naming ability could be partially explained by methodological discrepancies, where the studies that reported insignificant findings were outdated (more than 20 years old) and used only accuracy as a measure (Albert & Milberg, 1998; Park & Shaw, 1992). Hence, there is a crucial need to implement temporal measures, such as reaction times and word durations, to get a comprehensive picture of the actual effect of ageing on naming.

The inability to recall the names of certain everyday items, also known as anomia, is a common side effect in various neurological conditions such as aphasia (Goodglass & Wingfield, 1997), dementia (Papagno & Capitani, 2001), and traumatic brain injuries (Miceli & Castelfranchi, 2000; Papagno & Muggia, 1999). Anomia is also a common complaint in healthy older adults. Many healthy older speakers often complain about a subjective decline in their word-finding abilities, by which they are unable to find the targeted word at the right time to produce fluent speech.

In everyday conversations, healthy older adults may be able to conceal their word retrieval difficulties via synonyms or circumlocutions; this is in addition to contextual semantic cues which can aid lexical retrieval. However, word retrieval difficulties cannot be veiled during picture-naming tasks. Furthermore, the manipulation of semantic context in picture-naming can in fact reveal the exact effect of ageing on naming deterioration. Evidence from current research suggests that older adults are less accurate in naming pictures of objects or actions than younger adults (Barresi, Nicholas, Tabor Connor, Obler, & Albert, 2000; Connor et al., 2004; MacKay, Connor, Albert, & Obler, 2002) and are slower to name the presented images (Morrison, Hirsh, & Duggan, 2003). Tsang and Lee (2003), measured the effect of ageing on naming in a confrontational naming task on gender- and education-matched heathy younger and older adults. The researchers used accuracy and reaction time as indices of measurement. Their findings indicated that younger adults performed better than older adults, with higher accuracy and lower reaction times. Additionally, James (2004) confirmed that older adults experienced more retrieval failures for proper names than younger adults. These results support older studies that have exhibited the same results (Barresi, Obler, & Goodglass, 1998; Evrard, 2002). The manipulation of linguistic variables, such as utterance length and complexity, have also been proven to affect the reaction times and accuracy of older adults (Cerella, Poon, & Williams, 1980).

On the other hand, studies have shown that the speech of healthy older adults is less fluent and more verbose: they make longer pauses, use more semantically underspecified words such as ‘thing’, and experience the tip-of-the-tongue phenomenon more often than younger speakers (Arbuckle, Nohara-LeClair, & Pushkar, 2000; Bortfeld, Leon, Bloom, Schober, & Brennan, 2001; Burke & Shafto, 2004; Mortensen, Meyer, & Humphreys, 2006). Congruently, studies that have measured the fluency of speech in healthy young and older adults during everyday discourse have confirmed that older adults tend to speak slower and less fluently than younger speakers (Mortensen et al., 2006). The disfluencies present in the discourse analysis of the older adults’ speech include repetition of words and/or syllables, prolonged pauses, and the use of non-lexical words such as ‘um’ and ‘huh’, which are often associated with word retrieval difficulties (Bortfeld et al., 2001; Cooper, 1990; Kemper, 1992). The generalised slowing of speech in healthy older adults and the decline in fluency has been associated with an increase in demands and effort required to generate syntactic structures (Davidson, Zacks, & Ferreira, 2003).

In conclusion, older adults often report experiencing increased difficulty in finding words that they already know (Sunderland, Watts, Baddeley, & Harris, 1986). Evidence from ageing research has indicated that older adults are in fact more vulnerable to lexical retrieval failures during single word production and everyday discourse (Barresi et al., 2000; James, 2004; Schmitter-Edgecombe et al., 2000). Specifically, this word retrieval problem is not due to deficits in formulating the idea to be expressed, but rather reflects an inability to map a well-defined idea or lexical concept onto its phonological form with the intention of speech motor formulation (Belke & Meyer, 2007; Salthouse, 1982; Tree & Hirsh, 2003).

2.2.2 Ageing and Speech Motor Decline

In addition to the decline in linguistic processing that accompanies the normal ageing process, the regression in cognitive, sensory, and speech motor abilities further affect the performance of healthy older adults in everyday speech production tasks. Studies of speech production have documented that the motor system gradually develops throughout childhood and subsequently deteriorates with healthy ageing (Contreras-Vidal, Teulings, & Stelmach, 1998). Physical and physiological changes in the structure and functional integrity of the brain (Hof, 1997; Liu, Erikson, & Brun, 1996; Raz et al., 1997; Raz, Gunning- Dixon, Head, Williamson, & Acker, 2001) and the peripheral neuromuscular system (Delbono, 2003; Tracy, Maluf, Stephenson, Hunter, & Enoka, 2005; Vaillancourt, Larsson, & Newell, 2003) additionally occur as a consequence of the normal aging process, which instigates widespread changes. All these physical and physiological changes manifest as a decline in the speech motor function ability of healthy older adults (de Miranda Marzullo et al., 2010; Galganski, Fuglevand, & Enoka, 1993; Oliveira, Hsu, Park, Clark, & Shim, 2008).

As a consequence of the physiological changes to the anatomical structures of speech, the neuromuscular system, and the brain, speech motor performance is often compromised in healthy adults. Innumerable research studies focusing on healthy ageing have reported that older adults who fall between 60 and 95 years of age perform significantly slower and with greater variability in the execution of speech motor movements (Jaw/lip/larynx coordination, and stability) compared to the speech motor movements of younger adults aged between 20 and 35 in naming and repetition tasks (Wohlert, 1996; Smith et al., 1996; Wohlert & Smith, 1998). Empirical studies have also confirmed that movement stability, processing speed, attentional resources, and working memory capacity are implicated in generalised age-related changes, manifested in inaccurate movement execution of speech sounds and words (Craik & Byrd, 1982; Enns, Brodeur, & Trick, 1998; Salthouse, 1996), an increase in reaction time, movement duration, and accuracy of performance (Conteras- Vidal, Teulings, & Stelmach, 1998; Darling, Cooke, & Brown, 1989; Wishart, Lee, Murdoch, & Hodges, 2000).

It is not surprising given the above-mentioned age-related decrements that many older adults experience difficulties and breakdowns in speech production, such as a reduced speaking rate (Searl et al., 2002) and increased durations of segments, syllables, and sentences compared to younger adults (Smith et al., 1987). Ageing literature has stated that the increase in word durations and the reduction of speaking rate is triggered by a reduction in the speed of the peripheral sensory and motor processes, as well as neuronal loss, which in turn affects perceptual abilities, lexical processing time, and response execution (de Miranda Marzullo et al., 2010; Galganski, Fuglevand, & Enoka, 1993). Other studies measuring the changes in motor control in healthy ageing also proved that age-related impairments, such as decreased accuracy of movement amplitudes and increased temporal variability in the speech production of healthy older adults, are related to a decline in oro-facial motor control (Fozard et al., 1994; Smith et al., 1995; Robin & Downey, 2000).

A study by Kirrie Ballard and colleagues (2001) investigated the changes in the motor control of articulators (lower lip, jaw, and larynx) across the human lifespan. The sample was made up of 52 healthy individuals, divided into three categories: children (aged between 8.2 to 17.0), younger adults (aged between 17.1 to 45.0), and older adults (45.1 to 84.3). Motor control of the targeted articulators (lip, jaw, and larynx) was examined using a non-speech task which imitates speech but does not impose linguistic units or demands of coordinating multiple structures simultaneously. The participants were required to move the articulator of interest to track a moving target on a screen. Results of the study indicated that the accuracy of movement amplitude and variability tended to increase during development and decline with ageing. The findings discussed above are indicative of a significant decline in fine speech motor planning and speech motor execution with age.

The decline in linguistic and speech motor control processes in healthy older adults has been studied rigorously; however, they have been studied separately and independently. As such, the interaction of linguistic processing and speech motor control in healthy ageing is the objective of the current study. Clinically, such measures of interactions are needed to facilitate our understanding of the changes in speech motor control and linguistic processing that accompany the ageing process in healthy individuals. Furthermore, data on age-related changes in speech motor control and lexical access would aid in the identification of impairments in motor speech disorders and in differential diagnoses.

2.2.3 Interaction of Linguistic and Speech Motor Processes in Healthy Ageing Adults

The findings of linguistic and speech interactions in healthy and impaired children and adults are of both theoretical and clinical significance. What is not yet clear, however, is how advancing age may influence these interactions. Questions still remain as to whether or not normal ageing adults display differences in their speech planning and movements as the linguistic difficulty of their utterances is manipulated. The investigation of the interactions between linguistic and speech motor processes in healthy ageing adults has the potential to increase the understanding of speech deficits in disordered speakers by clarifying and distinguishing which changes may be attributed to the typical ageing process itself, as opposed to reflecting a communication disorder.

Recent studies measuring the effect of ageing on the interaction of linguistic and speech motor processes have demonstrated that factors which might influence linguistic processing can also modulate speech motor aspects of the word that is ultimately being produced. In a study by Sadagopan and Smith (2013) the effect of ageing on speech motor production through the manipulation of word length and complexity was investigated. The participants, 16 healthy younger adults (range = 18-24) and 16 healthy older adults (range = 66-73), repeated six novel non-words that varied in length and phonemic complexity (i.e., number of phonemes, number of consonant clusters, age of consonant cluster acquisition). Measurements of lip movement, coordination, duration, and accuracy of production were assessed. Results indicated that both younger and older participants were affected by the length and complexity of the non-words, with the older adults being significantly affected as the non-words increased in complexity. Additionally, lip coordination and duration were significantly affected in older participants as length and complexity increased. The results of their study provide robust evidence that the process of healthy ageing significantly affects the older adults in terms of accurately and rapidly repeating words that gradually increase in length and complexity.

Likewise, Dromey, Boyce, and Channell (2014) investigated the effect of the ageing, linguistic complexity, and speech motor control on articulatory stability across utterances that varied in length and grammatical complexity. Participants in their study were divided into three age groups: 20 young adults aged between 20–30 years, 20 middle-aged adults aged between 40–50 years, and 20 older adults aged between 60–70 years. The participants repeated five sentences with equal lengths but differed in grammatical complexity (i.e., number of clauses imbedded in the sentence) while simultaneously recording lip kinematics. Results confirmed that the participants from the 60-year-old group had significantly longer utterance durations in all utterances with varying complexity when compared to younger adults. Additionally, as grammatical complexity increased so did the movement variability and coordination of the lips in older adults.

The above studies focused on movement kinematics to investigate the interaction of linguistic processes on articulatory movement. However, there are no other studies to our knowledge that have measured the interaction of linguistic processes on healthy ageing. Therefore, this study will be using a naming task while manipulating the linguistic and speech motor aspects of the targeted stimuli to measure the interaction of linguistic and speech motor processes and their influence of the healthy ageing process.

To conclude, word production is commonly investigated using two distinctive approaches: the linguistic approach and motor control approach. Research on word production and the interaction of both linguistic and speech motor control processes has gained traction in the past few years, with researchers attempting to measure the influence of these processes on one another. However, there is a paucity of research that focuses on the influence of the interaction between linguistic and speech motor control process on healthy older adults beyond their inclusion as age-matched controls.

2.3 The Current Investigation, Research Questions and Predictions

The current study aimed to investigate the effect of ageing on linguistic and speech motor processes through the implementation of the semantic blocked non-cyclical naming paradigm. The manipulation of semantic contexts was used as a measure of linguistic processing during lexical access, and articulatory complexity as a measure of speech motor performance. The analysis investigated the effect of semantic context (homogenous vs heterogeneous) and articulatory complexity (simple vs complex) and their interaction on healthy younger and healthy older adults. Participants were 30 healthy younger adults (HYA, hereafter) and 30 healthy older adults (HOA, hereafter) that were British monolingual speakers of English, matched on age and years of education.

The involvement of both healthy young and healthy old adults in this study allows for the capture of variations in word production performance attributable to age and cognitive processes. Because differences in both age and neurological condition exist between normal adults, young adults, and neurologically impaired elderly patients, one cannot precisely determine whether observed differences are a function of age, neurological condition, or both. Therefore, it is of great importance to measure the effect of healthy ageing on the interaction of linguistic and speech motor processes as the majority of patients who acquire speech-related neurological impairments are older adults and the studies of the speech of such patients should be compared to those of unimpaired adults of similar ages. However, because minimal information of this nature is currently available, comparisons are often made with data from much younger adults. From a clinical and scientific perspective, it is thus critical to obtain information that allows researchers to control for the potential effects of normal ageing, to be able to isolate the damages from the nervous system on word production.

This study focuses on the issue of the effect of normal ageing on linguistic and speech motor control processes. Group differences will be analysed for accuracy, linguistic processing speed (RT), and speech motor performance (WD) in the naming responses. It was hypothesised that ageing would have a negative effect on naming accuracy, reaction time, and word duration. As such, younger adults would outperform older adults in terms of accuracy, RT, and WD in the naming task. The aim and predictions for this study were the following:

1- To investigate the influence of manipulations of the linguistic and speech motor processes on the performance of HYA and HOA in a picture-naming task on accuracy, reaction time, and word durations.

We hypothesise that ageing would be significantly associated with a decline in accuracy, increase in RT, and increase in WD, reflecting a decline in linguistic and speech motor processes during word production (Barresi et al., 2000; MacKay et al., 2002). Age-related differences will be observed, with both the HYA and HOA showing a significant main effect of blocking but with the older subjects showing larger effects in the blocked conditions by having longer RT's. We predict that manipulations of linguistic processes will affect naming accuracy and RT. We also predict that manipulations of speech motor process will induce lower naming accuracies and WD.

2.4 Methods

2.4.1 Participants

Sixty healthy, right-handed, monolingual British adults participated in this study. The participants were divided into two equal groups: 30 HYA and 30 HOA. The HYA ranged between 21 to 36 years of age (M=23.00, SD= 3.98, 23 females, 7 males) with an average of 15.13 years of education (M= 15.13, SD= 2.33, range= 14-20). The HOA ranged between 57 to 91 years of age (M= 74.40, SD= 8.71, 17 females, 13 males) with an average of 16.20 years of education (M= 16.23, SD= 2.79, range= 13-21). The HOA were all independent community- dwelling adults. All the participants completed a questionnaire on their health and reported no history of language, neurological and/or psychiatric deficits or substance abuse, and no uncorrected hearing or visual impairments. Prior to participation in the experiment, the participants were administered with speech and cognitive screening measures. Their cognitive status was tested using the Mini-Mental State Examination (MMSE) (Folstein, Folstein, McHugh, 1975), a 30-point questionnaire where all the participants performed above the cut-off limit (i.e. >24, adjusted for education). The use of the MMSE was a means of screening the participants' cognitive, mental, and memory abilities, as a score lower than 24 on the MMSE can indicate the presence of cognitive impairment.

The diadochokinetic rate (DDK) was used as a verbal speech measure where participants were asked to repeat particular sounds as fast and as accurately as possible for a total of three trials of five seconds each (Fletcher, 1972). An average of the three trails was then calculated and divided by the number of seconds. A reduced rate on the DDK can be indicative of ageing changes or speech impairments such ataxia, apraxia of speech, and dysarthria. Demographic information with the MMSE and DDK scores is provided in Table 2.1 as well as Appendix 2.1 and 2.2. Statistical analysis shows that there is no significance between the groups in regard to: education (t=1.658, p <.10), Mini Mental State Exam scores (t= -1.66, p <.10), and diadochokinetic rates (t=1.09, p <.28). As expected, there was a significance of age between groups.

Recruitment of the HYA was via the participant pool from the School of Psychology Research Panel. Compensation in the form of two course credits was provided. The HOA were recruited using the University of Reading Ageing Research Panel. Monetary compensation of £10 was provided for their time and travel. Ethical approval for the study was obtained from the Ethics Committee at the School of Psychology and Clinical Language Sciences, University of Reading. All participants provided informed consent before the experiment and their data was analysed anonymously.

Table 2.1: *Demographic detail of the HYA and the HOA participants*

Variable	Healthy Younger Adults (HYA)	Healthy Older Adults (HOA)	
No. of Participants	30	30	
	Mean (SD)		t, (*p-value*)
Age (years)	23.12 (3.98)	74.4 (8.71)	29.316 (.00)
Gender (M/F)	7/23	13/17	
Education	15.13 (2.33)	16.23 (2.78)	1.66 (.10)
MMSE[1] Score	29.30 (0.75)	28.90 (1.21)	-1.66 (.10)
DDK[2]- / pʌ/	6.04 (0.64)	5.95 (0.67)	.53 (.60)
DDK- / tʌ/	6.00 (90.49)	5.82 (0.89)	.33 (.74)
DDK- /kʌ/	5.84 (0.77)	5.86 (0.38)	.77 (.44)
DDK- /pʌtəkə/	6.30 (0.73)	5.30 (0.93)	1.09 (.28)

Note: [1]- Mini Mental State Exam (Folstein M.F., Folstein S.E., McHugh P.R., 1975), [2]-DDK stands for diadochokinetic rate (Fletcher, 1972).

2.4.2 Stimuli

The stimuli used in this experiment were 100 nouns depicted by black-and-white line drawings sourced from the Philadelphia Naming Test (Roach et al., 1996), Snodgrass and Vanderwart Picture Database (1982), and the International Picture Naming Project (Szekely et al., 2004). The stimuli were used to create 10 semantic categories (animals, body parts, birds, fruits and vegetables, furniture, musical instruments, things to wear, tools, toys, transportation) with 10 exemplars in each. Each of the semantic categories included 5 complex words and 5 simple words.

2.4.2.1 Index of Phonetic Complexity. The articulatory complexity and the classification of the stimuli as either simple or complex was assessed individually for each item using the IPC by Jakielski (Jakielski, 1998). In the IPC scheme, a numerical value is assigned to sounds and structures based on the phonetic transcription of the targeted words produced by the participant in the following eight factors: (1) consonant place (every dorsal consonant in a word is given one point whilst no points are given for other consonants such as labials, coronals, and glottals), (2) consonant manner (every fricative, affricative, and liquid consonant in a word is given one point whilst no points are given for other consonants such as stops, nasals, and glides), (3) vowel by class (each word that has a rhotic vowel is given one point and words with monophthongs and diphthongs are given no points), (4) word shapes (each word that ends with a consonant is given one point, whereas words that end with a vowel are given no points), (5) word length (a word with three or more syllables is given one point and words with one or two syllables are given no points), (6) consonant reduplication versus variegation, (7) singletons versus clusters, and (8) cluster types. The scoring rubric for the eight phonetic factors is provided in Table 2.2. Phonetic properties such as the production of labials, stops, and nasals are considered early developmental milestones and receive a low IPC score, whereas phonetic properties such as late-emerging sounds, multisyllabic words, and consonant clusters are considered late-developing phonetic milestones and are given higher IPC scores. For example, for the "consonant by place" factor, labials, coronals, and glottals are common early developmental phonetic milestones and therefore regarded as easy. When consonants with these places occur, they receive an attribute score of zero. Dorsals, on the other hand, rarely occur in early phonetic development, and thus are considered complex and get an attribute score of one point whenever they occur in a word. The IPC composite score is calculated by summing up the scores on the eight separate factors (see Table 2.2).

To ensure that the categories had an equal number of complex and simple words the following steps occurred: (1) the stimuli were phonetically transcribed, (2) each word was given a score for each of the eight factors of the IPC, (3) a total IPC score was calculated by adding up the scores of the eight separate IPC factors, (4) based on the total IPC score, words were either classified as phonetically simple or complex. For example, for the word 'chest' the following steps were completed: (1) 'chest' was phonetically transcribed as /ʧest/, (2) for the word /ʧest/, 2 points were given for the consonant manner category, 1 point was given in the word shape category, and 1 point was given in the contiguous consonants category, (3) a total of 4 points was given for the word /ʧest/, (4) the word /ʧest/ was classified as complex since it accumulated more than 3 points. The cut-off between phonetic simplicity and phonetic complexity of words is very problematic; hence for the purpose of this study we have followed the previous literature and classified the scores between 0-3 as phonetically simple and scores of 4 and above as phonetically complex (Bose et al., 2011). Totally, the 100 stimulus items were equally divided into two groups of complexity, where there were 50 phonetically complex words and 50 phonetically complex words in total. Therefore, within each semantic category there were 5 simple words and 5 complex words. The stimuli items for the "Animals" category and their IPC scoring can be seen in Table 2.3. The IPC scoring for all the stimuli used in the study can be found in Appendix 2.3.

Table 2.2: *The IPC Categories and Scoring Rubric*

Factor	No Score	One Point Each
1. Consonant by Place	Labials, coronals, glottals	Dorsals
	Labials: p b m w f v	Dorsals: k g ng
	Coronals:	
	Glottals: h ?	
2. Consonant by Manner	Stops, nasals, glides	Fricatives, affricates,
	Stops: p b t d P k g ? h	Fricatives: T Δ f v s z Σ Z
	Nasals: m n Ng	Affricates: tΣ dZ
	Glides: w j	Liquids: l r
3. Singleton Consonants by Place	Reduplicated	Variegated
4. Vowel by Class	Monophthongs, diphthongs	Rhotics
	Monophthongs: i I e E æ ↔ œ a u U o O	Rhotics: Φ Ir Er ar ur Or aUr
	Diphthongs: aI aU OI	
5. Word shape	Ends with a vowel	Ends with a consonant
6. Word Length (Syllables)	Monosyllables, disyllables	>=3 syllables
7. Contiguous Consonants	No Clusters	Consonant Clusters
8. Cluster by Place	Homorganic	Heterorganic

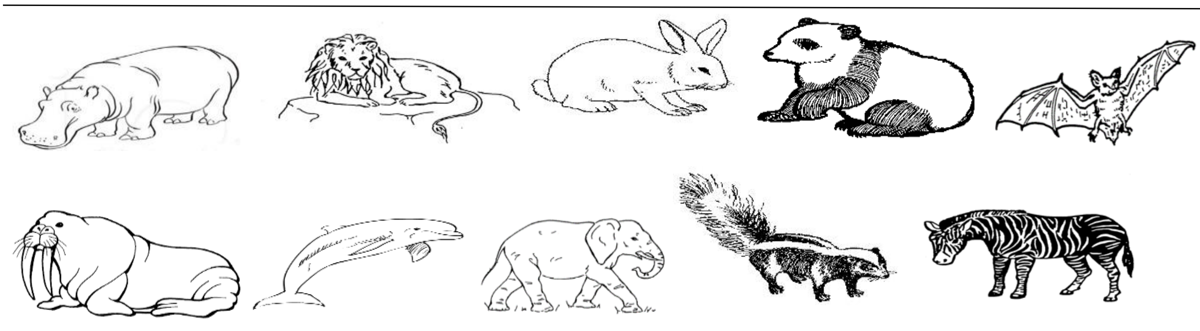
Note: These scoring criteria were obtained from K. Jakielski (1998)

Table 2.3: *Examples of Index of Phonetic Complexity (IPC) scoring for the "Animals" category used in our study*

The categories are coded as follows:

1. Consonant by place
2. Consonant by manner class
3. Vowel by class
4. Word shape
5. Word length in syllables
6. Singleton consonants by place variegation
7. Contiguous consonants
8. Cluster by type

Word	Phonetic transcription	IPC Category and points obtained								Total	Word type
		1	2	3	4	5	6	7	8		
Hippo	/ˈhɪpəʊ/	0	1	0	0	0	0	1	0	2	Simple
Lion	/ˈlaɪən/	1	0	1	0	0	0	0	0	2	Simple
Rabbit	/ˈræbɪt/	0	1	0	1	0	1	0	0	3	Simple
Panda	/ˈpændə/	0	0	0	0	0	0	1	0	1	Simple
Bat	/bæt/	0	0	0	1	0	1	0	0	2	Simple
Walrus	/ˈwɔːlrəs/	0	3	0	1	0	0	1	0	5	Complex
Dolphin	/ˈdɒlfɪn/	0	2	0	1	0	0	1	1	5	Complex
Elephant	/ˈelɪfənt/	0	2	0	1	1	0	1	0	5	Complex
Skunk	/skʌŋk/	3	1	0	1	0	0	2	1	8	Complex
Zebra	/ˈziːbrə/	0	2	0	0	0	0	1	1	4	Complex



2.4.2.2 Lexical characteristics. Lexical characteristics for all the stimuli items used in the study were gathered using online psycholinguistic databases such as N-Watch (Davis, 2005), Medical Research Council psycholinguistic database (Wilson, 1988), and the Collins Birmingham University International Language Database (University of Birmingham, 1980). The use of these databases as a psycholinguistic tool provided a broad range of lexical statistics for the 100 items on our stimuli list, including measures of word frequency, number of syllables, phonological structure, age of acquisition (AOA), and imageability. The lexical variables for all the words in our stimuli list can be found in Appendix 2.4. Statistical tests were performed to ensure that there was no systematic variation of Log frequency (t = -1.42, p >.16), imageability (t = .98, p >.33), age of acquisition(t =-.86 , p >.39), subject familiarity (t = 2.02 , p >.50), and total CELEX frequency, which includes both the total spoken and written frequency (t =1.83 , p >.71) between the simple and complex words that were chosen to be included in our study (Table 2.4). However, there was a significance of complexity between simple and complex words in the IPC total score (t= -13.26, p<.00), number of syllables (t= -2.42, p <.01), and number of phonemes (t = -4.7, p < .00) which was to be expected, as complex words tend to be longer and have a higher total IPC score.

Table 2.4: *Lexical Statistics for the Words Used in the Stimuli List for the Study*

Variable	N	Simple (M)	Simple (SD)	N	Complex (M)	Complex (SD)	t- value	p-value
Index of Phonetic Complexity	50	2.14	.88	50	5.00	1.25	-13.26	.00
# of syllables	50	1.46	.58	50	1.78	.73	-2.42	.02
# of phonemes	50	3.72	1.03	50	4.92	1.47	-4.73	.00
Log frequency	50	1.18	.65	50	1.01	.53	-1.42	.16
Celex total	50	41.55	74.81	50	20.32	33.27	1.83	.10
Celex spoken	50	42.69	77.14	50	21.41	35.18	1.75	.10
Subject frequency	29	433.04	105.04	16	411.81	104.67	.65	.52
Subject familiarity	40	550.20	53.59	34	523.21	60.13	2.02	.05
AoA	29	250.10	60.36	23	262.96	46.86	-.86	.39
Imageability	40	602.63	28.82	34	595.18	35.63	.98	.33

Note: These lexical statistics were obtained using the following psycholinguistic databases: N-Watch (Davis, 2005), the Medical Research Council (Wilson, 1988) and the Collins Birmingham University International Language Database (University of Birmingham, 1980).

2.4.2.3 Creating the homogenous and heterogeneous categories. The stimuli were further divided to create ten homogenous and ten heterogeneous categories, with 10 words in each of the categories. In the homogenous condition, the stimuli were grouped into semantic categories (e.g., simple words: ball, tent, yoyo, kite, dice; complex words: carousel, puzzle, robot, swing, marbles). The items in these sets were meant to be semantically related. The homogeneous categories were: toys, fruits and vegetables, things to wear, birds, transportation, furniture, animals, body parts, musical instruments, and tools. The heterogeneous condition was created by randomly regrouping the stimuli from the semantic homogenous sets into new 10-item sets that included one item from each of the semantic categories (e.g., simple words: tape, drum, shoe, chair, lips; complex words: wagon, skunk, orange, chicken, carousel). The items in these sets were meant to be semantically unrelated. In total, twenty sets were created from the selected objects. Complexity was also balanced in the heterogeneous sets with five simple words and five complex words. The categories can be found in Appendix 2.5. Table 2.5 depicts all twenty categories that were created for the study.

Table 2.5: *Lists of the Homogenous and Heterogeneous Categories Used in the Study*

#	**Animals**	**Body parts**	**Furniture**	**Music**	**Clothing**	**Tools**	**Toys**	**Transport**	**Fruits & Veg**	**Birds**
1	Hippo	toe	bed	Radio	belt	hammer	ball	boat	Kiwi	robin
2	Lion	thumb	chair	Banjo	hat	nail	puzzle	wagon	Cherry	duck
3	rabbit	elbow	lamp	Drum	wig	ruler	Yoyo	van	Tomato	gull
4	panda	beard	mirror	Harp	shoe	saw	kite	car	Radish	owl
5	Bat	nose	window	Piano	tie	tape	Tent	train	Lemon	turkey
6	walrus	chest	clock	accordion	dress	axe	carousel	rocket	Broccoli	eagle
7	dolphin	finger	shelf	Flute	jacket	drill	dice	skis	Apple	ostrich
8	elephant	ankle	desk	trumpet	skirt	lock	robot	helicopter	Orange	penguin
9	skunk	heel	stool	violin	crown	pliers	marbles	Bicycle	Pumpkin	chicken
10	zebra	lips	table	whistle	glasses	shovel	swing	saddle	Grapes	crow

In each of the twenty sets, all the stimuli were balanced and controlled for a number of characteristics. Care was taken to ensure that all the stimuli items shared the following characteristics: (1) were visually distinct to prevent any misperception and errors (e.g. *orange* and *tangerine*), (2) did not have a similar phoneme onset (e.g. *panda* and *pig*), (3) did not rhyme (e.g. *cat* and *bat*), (4) were all monomorphemic (e.g. *paper* vs *paper clip*), (5) were not phonetically consecutive and (6) had an equal number of stimuli with varying complexity (5 simple vs 5 complex).

2.4.3 Design

A non-cyclical blocked naming paradigm was implemented where participants were required to name a series of pictures in two semantic contexts: homogenous and heterogeneous. In the homogenous context, all the pictures were from the same superordinate semantic category (e.g., Simple: *bat, hippo, lion, rabbit, panda;* Complex: *walrus, dolphin, elephant, skunk, zebra*). In the heterogeneous context the pictures came from different semantic categories (e.g., Simple: *boat, nose, cherry, panda, gull;* Complex: *pliers, flute, skirt, swing, clock*). The study included one main picture-naming task. In total, there were twenty sets in the study: 10 homogenous sets and 10 heterogeneous sets. Each of the sets were constructed in such a way as to have 10 exemplars with 5 of them considered phonetically simple and the other 5 phonetically complex. In the homogenous condition, 10 category exemplars were presented together in a set (e.g., Tools: Simple: *hammer, nail, ruler, saw, tape*; Complex: *axe, drill, lock, pliers, shovel*) to form 10 homogenous sets. In the heterogeneous condition, the categories were compromised by using one exemplar from each of the 10 homogenous categories (e.g., Simple: *toe, saw, banjo, wig, bed*; Complex: *rocket, apple, penguin, zebra, tent*).

Items were presented an equal number of times in both the homogenous and the heterogeneous conditions, with each target picture presented only twice, once in each of the conditions. For instance, the target picture of "*carousel*" was depicted in the naming task only twice, once in a homogenous condition (*ball, dice, yoyo, kite, tent, <u>carousel</u>, puzzle, robot, marbles, swing*) and once in the heterogeneous condition (*<u>carousel</u>, skunk, tape, drum, shoe, chair, lips, skies, orange, chicken*). For each of the naming and repetition tasks, three different sequences were created for the experiment. The presentation order of the homogeneous and heterogeneous sets within a naming task, and the order of the pictures within each set were randomly generalised using the randomisation function in Excel (see table 4.14). For example, in the naming task, one participant named three homogeneous blocks followed by three mixed blocks, whereas another participant named a homogeneous block followed by a heterogeneous block, then another heterogeneous block and so on. The three randomised sequences used in this study can be found in Appendix 2.6.

Each of the picture-naming experimental tasks consisted of a total of 4 blocks with 50 trials per block (i.e., 200 trials per each task). A short break could be taken after each of the blocks and between the two tasks. Participants were not corrected by the experimenter during the whole study. The administration time for the entire study was approximately 90 minutes.

2.4.4 Procedure

The study session was divided into three parts. First there was the familiarisation phase, followed by the picture-naming task, and the study concluded with a repetition task that was used as a control. The participants were seated comfortably at a table and the pre-recorded stimuli were presented via speakers and a computer screen.

2.4.4.1 Familiarisation phase. Prior to the experiment, to familiarise the participants with the stimuli and their targeted names, the participants were shown the pictures with the names of all the objects that would subsequently appear in the study via a PowerPoint slide show. The participants were familiarised with the stimuli by seeing their names written below them. They were then asked to only name the objects using the names listed on the PowerPoint. During the familiarisation phase, the participants were presented the pictures once in a random order in a self-paced manner with corrective feedback provided when necessary. The familiarisation phase was followed by four test blocks in the picture-naming task, which were separated by short breaks. This familiarisation procedure utilised in our study was derived from previously reported picture-naming experiments (Belke & Meyer, 2007; Crowther & Martin, 2014; Navarrete et al., 2012).

2.4.4.2 Picture-naming task. The testing began by presenting the participant with instructions. The instructions to the participants were as follows: "One at a time you will be presented a picture of an object on the screen. Please name the object as quickly and as accurately as possible using a single bare noun. If you are unable to name the object, do not worry and try the next one." When the participant was ready to initiate the trial, the experimenter pressed a key. Pictures were presented one at a time using the E-prime computer program and all responses were recorded using a digital recorder. For the purpose of this study we have adapted the trial sequence used in Belke (2008) where the following occurred in each naming trial: (1) a fixation point was displayed at the centre of the screen for 800 ms, followed by (2) a blank screen shown for 100 ms, and finally (3) a single target picture accompanied with an electronic beep displayed for 5000 ms. In order to prevent participants from anticipating the upcoming stimuli, the time interval between the alerting signal and the start of the presented image varied between 800 ms and 1000 ms. The next naming trial began 1500 ms after the onset of the participants' response of 3000 ms after the offset of the target. The precise trial naming cycle is presented in Figure 2.1.

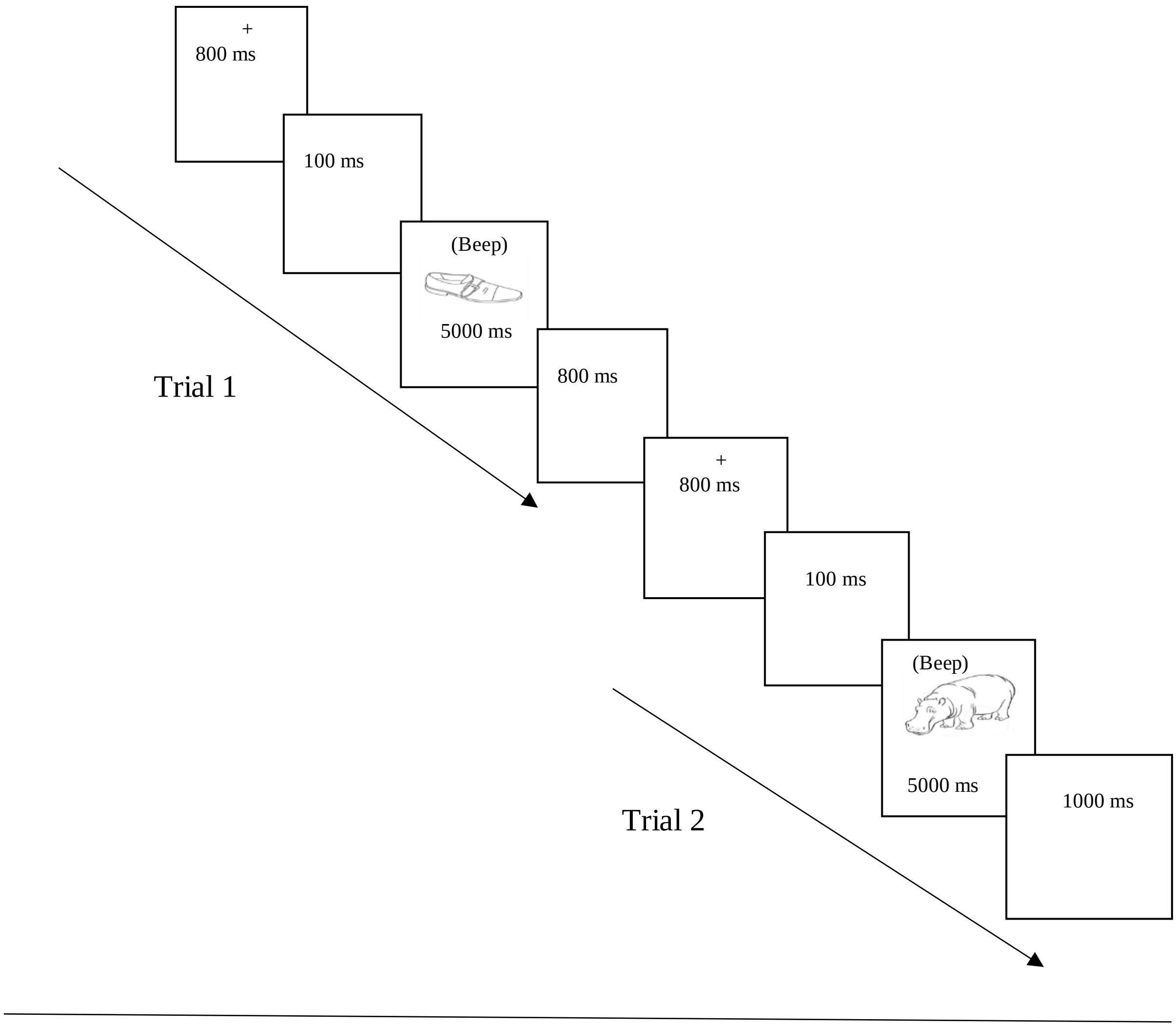


Figure 2.1 Sample of 2 consecutive trials in the heterogenous condition in blocked non-cyclical naming task.

The participants named 200 items with a break after every 50 items named, for as long as required. All of the responses were audio recorded for analysis (error coding and error analysis is discussed in upcoming sections). The precise scoring can be seen in Table 2.6 below.

2.4.4.3 Repetition as a control task. The performance of picture-naming is customarily perceived as involving multiple levels of linguistic processing (i.e., semantic, phonological) of the word production models (Schriefer, Meyer, & Levelt, 1990). However, word repetition, is assumed to be accomplished by the direct mapping of input phonology (sounds of the word heard) to output phonology, with the involvement of a single linguistic aspect (Nozari et al., 2011). Therefore, for the purpose of this study, we decided to use repetition as a control task where we tested the same items used in the naming task. However, the participants were required to repeat rather than name the targeted items. As repetition customarily takes advantage of the phonological step of the linguistic processing while surpassing the semantic step, we predicted there would be no indication of the influence or a possible interaction between semantic blocking and articulatory complexity on the repetition task.

Pre-recorded stimuli were presented to the participants one at a time through the use of speakers. Instructions to the subjects were as follows: “Please listen carefully. One at a time you will hear a word through the speakers. Please repeat the word you hear as quickly and as accurately as possible. If you are unable to repeat a word or miss a word, do not worry and try the next word.” For every trial, the same timed sequence used in the naming tasks occurred: a fixation cross was displayed for 800 ms, a black screen was then displayed for 100 ms, a pre-recorded target word as spoken by a native English speaker was played, the subject was asked to respond immediately, and the trial would then terminate 800 or 1000 ms after the recording was heard. The same scoring used for the naming trials was also used for this task. To ensure the reliability of the recorded audio for the repetition task, British monolingual colleagues listened to the repetition of words in order to guarantee the words were clear and accurately produced.

Both the naming and repetition tasks were programmed using E-Prime software on a Toshiba Protégé. The participants’ responses were simultaneously recorded using Olympus mini digital recorder (DM-5).

2.5 Data Preparation

2.5.1 Accuracy and Error Analysis

Responses for every trial were transcribed verbatim. Each trial was then coded for accuracy. RT’s and WD’s were analysed only for the accurate responses in both the naming and the repetition tasks. Responses were scored as correct if they replicated the target name. Otherwise, the failure to respond or any responses other than the targeted word were considered inaccurate and were categorised using a specific error coding system. The correct responses were coded with a 10. The coding system for the incorrect responses can be seen in Table 2.6.

Table 2.6: *Error Coding and Examples*

Error Type	Code	Example
Audible hesitation	11	um, ah, sigh, laugh followed by stimulus name
Responses that included an audible hesitation with the repetition of the initial phoneme of the targeted word at the start	12	b... belt
Responses that included the initial phonemes of a within-set semantic competitor or a within-set phonological competitor (e.g., ow…ostrich)	13	Within-set semantic competitor (e.g., d… chair) within-set phonological competitor (e.g., ow…ostrich)
Responses that included the initial phonemes of any word including a semantic competitor that is outside the set	14	bal… marbles
Responses that included indefinite articles	15	A ball
Responses that included define articles	16	The ball
Alternative names	17	spectacles for glasses
Failure to name a stimulus	20	
Responses that were description of the stimulus	21	A black bird instead of crow
Semantic error (category coordinate, within stimulus material set)	30	Ankle instead of heel
Semantic error (category coordinate, outside stimulus material set)	31	Onion instead of radish
Semantic error (associative)	32	Light for lamp
Semantic error (super and subordinate error)	33	Bird instead of robin
Unrelated error	60	Tree instead of radish

2.5.2 Outlier Analysis

A two-step procedure was used to deal with outliers on both the naming and repetition tasks (Miyake et al., 2000). First, upper and lower criteria were set for each task. Responses were excluded from the analyses when response times were less than 300 ms or greater than 5000 ms. Second, the mean and standard deviations were calculated for each participant in each condition (homogenous and heterogenous) and any response times that deviated to ± 3 standard deviation above or below the mean per condition were excluded. In the naming task, these two procedures affected less than .98% of the data for the HYA (105 responses were eliminated) and .99% of the data for the HOA (91 responses were eliminated). In total, out of the 6000 trials in the HYA naming task, 5197 responses were used for the analysis, i.e. 13% of the data were discarded. The total percentage of data discarded for the HOA was 18%, which means 4941 responses were utilised in the final naming analysis; whereas in the repetition task, the HYA only had 2 errors that were also outliers and were removed from the analysis. The HOA on the other hand, had 102 outliers that were excluded from the analysis which amounts to only 1.60% of the data being eliminated. A similar criterion for the exclusion of reaction times was implemented by Meyer & Damian (2007) and Belke & Stielow (2013).

2.5.3 Measurement of the Responses

Reaction time and word duration were analysed manually using the computer software programme, PRAAT (Boersma & Weenink, 2005). Voice recordings for the naming task for each participant was uploaded into PRAAT which outputs a waveform and a spectrogram for every single sound production in the recording (a sample of the waveform/spectrogram for one single word can be seen in Figure). This was used to measure each RT and WD for each and every target named. Analysing each recording separately and manually by hand rather than using a voice key was essential to accurately code responses, as responses may include degraded sounds such as coughs, the addition of articles, and hesitations. A sample of WD and RT analysis during a naming trial for the word "dog" using PRAAT can be seen in Figure 2.3.

2.5.3.1 Reaction time analysis. Reaction time is defined as the time that elapses between when the participant was presented the stimulus (indicated by the beep) and when the response was initiated in response to the stimulus. Reaction time was measured from the beginning of the beep that accompanies the stimuli to the beginning of the participants' utterance. A sample of how RT was measured can be seen in Figure 2.2.

2.5.3.2 Word duration analysis. Word duration is defined as the length of time it takes the participant to name/repeat the given stimuli. Measurements were initiated from the participants' voice onset of the initial consonant sound of the targeted word to the end of the utterance. A sample of how WD was measured can be seen in Figure 2.2.

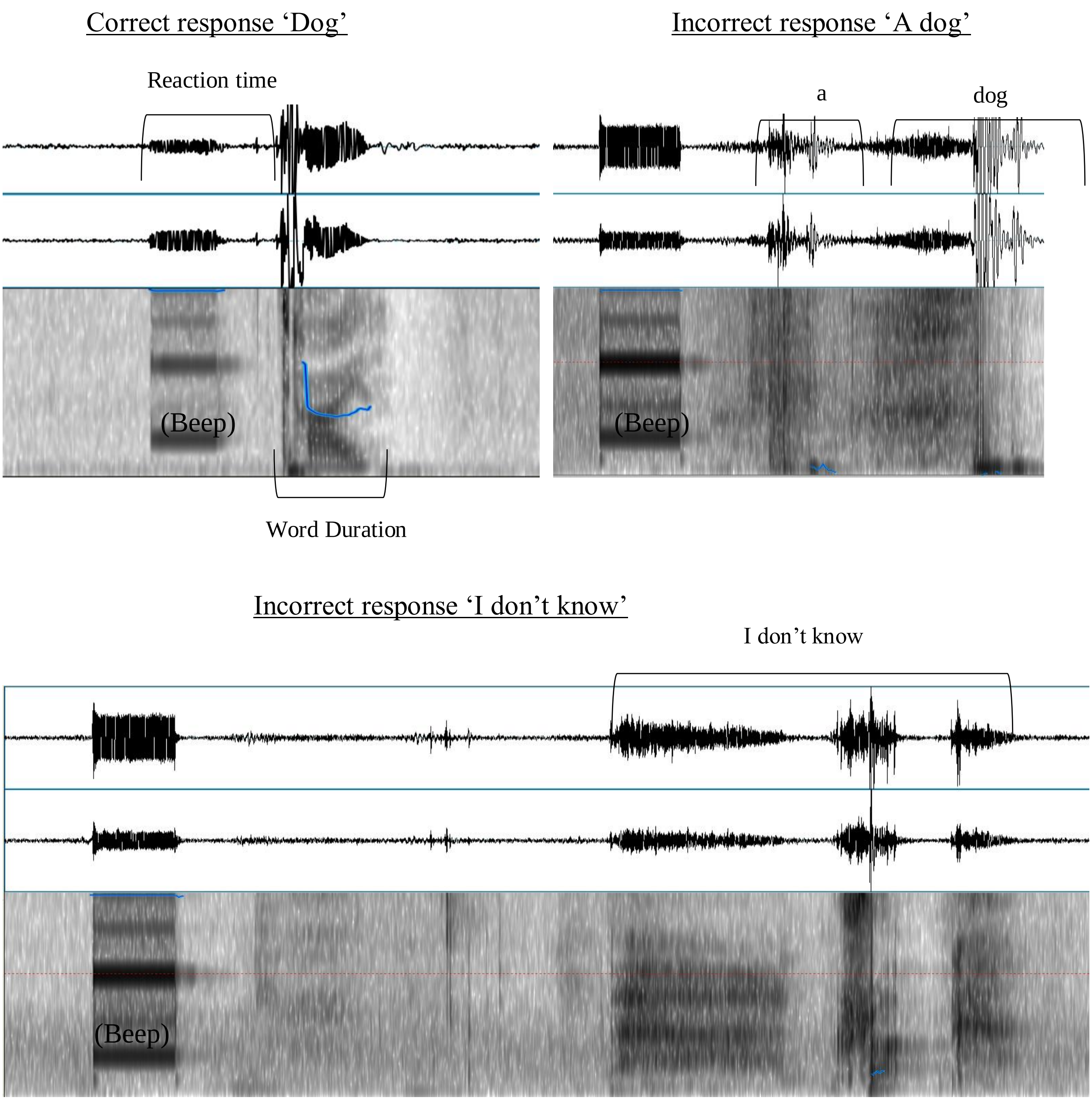


Figure 2.2 Sample PRAAT analysis with response times and word duration for three different responses for the naming of “dog”.

Methodological challenges using PRAAT were apparent. The performance of the audio input system was occasionally degraded due to noise from the participants such as coughing, throat clearing, and body movement. To ensure reliability of the measures, the audio waves were assessed in tandem and reliability measures were conducted. Figure 2.3 displays several PRAAT samples for responses that included noise from the participants, hesitations, and additions such as ‘the dog’ for the naming of ‘dog’.

2.5.3.3 Reliability of the Reaction Time and Word Duration Analysis. Intra-rater reliability was performed on 12% of each participant’s naming data and the correlation coefficients were 0.92 for the reaction times and 0.87 for the word durations. Inter-rater reliability was also completed for the accuracy, response times, and word duration in both the naming and repetition tasks. The inter-rater reliability was accomplished by having a second rater trained in the measurement of RT and WD using PRAAT on a set of items from the naming task by the primary experimenter. Inter-rater reliability was performed on 18% of each participant's data and the correlation coefficients were 1.00 for accuracy, 0.96 for reaction time, and 0.90 for WD.

2.5.4 Statistical Design

A repeated measure analysis of variance (ANOVA) was performed for each variable of interest (accuracy, RT, and WD). A two-way between subject's ANOVA was conducted with alpha levels set at 0.05 for significance. For statistically significant results, within group one-way ANOVAs were conducted on the HYA and HOA separately.

2.5.5 Factors

The independent variables measured were blocking condition (homogenous vs heterogeneous) and complexity (simple vs complex). Accuracy, reaction times, and word durations were the dependent variables. For the between group ANOVA the factors of interest were group, blocking, complexity, blocking x group, complexity x group, blocking x complexity, and blocking x complexity x group.

2.6 Results

The mean and standard deviation values for both groups of participants (HYA and HOA) in both semantic contexts (homogenous and heterogeneous) and complexity levels (simple and complex) for all dependent variables (accuracy, reaction time, and word duration) are presented in Table 2.7 below. The results of the ANOVA statistical tests are provided in Table 2.8 below. One way within group ANOVA's (HYA and HOA separately) were conducted to further investigate the interactions found.

Table 2.7: *Descriptive Statistics for Healthy Younger and Healthy Older Adults on the Blocked Non-cyclical Naming Task*

Healthy Younger Adults				**Healthy Older Adults**			
Accuracy							
	Simple (n=50)	Complex (n=50)	Total (n=100)		Simple (n=40)	Complex (n=50)	Total (n=100)
Homogenous	44.2 (4.1) 88%	43.9 (3.9) 87%	88.63 (7.03) 89%	**Homogenous**	42.2 (4.6) 84%	41.4 (5.4) 82%	83.63 (9.64) 84%
Heterogeneous	44.5 (4.2) 89%	44.1 (3.2) 88%	80.07 (7.63) 80%	**Heterogeneous**	42.8 (3.9) 86%	41.3 (5.6) 82%	84.13 (9.21) 84%
Overall complexity	89.2 (8.04)	88.1 (6.70)		**Overall complexity**	85.0 (8.27)	82.7 (10.68)	
Overall mean (n=200) 176.7 (14.17) 88%				Overall mean (n=200) 167.76 (18.41) 83%			
Reaction Time in ms.							
	Simple	**Complex**	**Total**		**Simple**	**Complex**	**Total**
Homogenous	694.23 (65.28)	713.23 (69.74)	703.76 (65.65)	**Homogenous**	758.02 (63.83)	800.60 (77.80)	779.27 (69.47)
Heterogeneous	671.0 (63.01)	694.66 (66.71)	682.80 (63.01)	**Heterogeneous**	750.81 (69.53)	781.12 (76.93)	765.73 (70.51)
Overall complexity	682.72 (61.98)	704.16 (65.73)		**Overall complexity**	754.36 (65.50)	791.48 (75.59)	
Overall mean 693.35 (62.87)				Overall mean 772.621 (68.89)			
Word Duration in ms.							
	Simple	**Complex**	**Total**		**Simple**	**Complex**	**Total**
Homogenous	454.05 (47.52)	468.65 (46.13)	462.38 (45.59)	**Homogenous**	487.03 (40.55)	510.17 (44.96)	498.51 (42.13)
Heterogeneous	440.19 (46.56)	452.88 (48.67)	446.57 (46.74)	**Heterogeneous**	481.80 (43.77)	499.69 (46.89)	490.55 (43.88)
Overall complexity	447.19 (45.86)	460.88 (46.44)		**Overall complexity**	484.39 (41.68)	505.03 (45.02)	
Overall mean 454.02 (45.60)				Overall mean 494.57 (42.645)			

Note: means are written with standard deviations in parentheses. Means and standard deviations are after the removal of outliers.

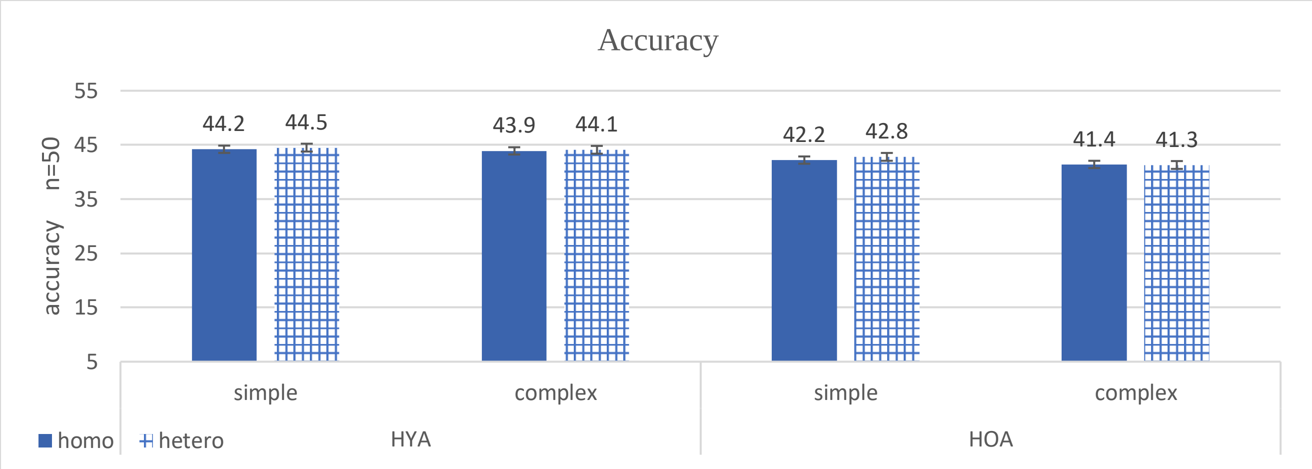


Figure 2.3 Mean accuracy by context (homogenous and heterogeneous) and complexity for each group (healthy younger and older adults). Error bars represent the standard error of the mean.

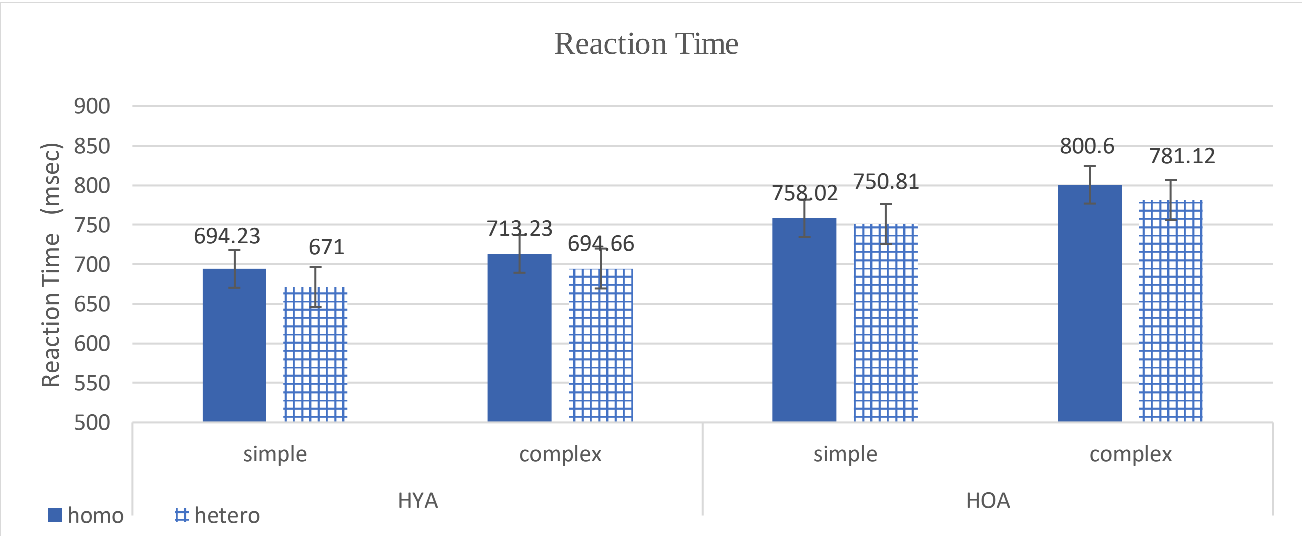


Figure 2.4 Mean RT by context (homogenous and heterogeneous) and complexity for each group (healthy younger and older adults). Error bars represent the standard error of the mean.

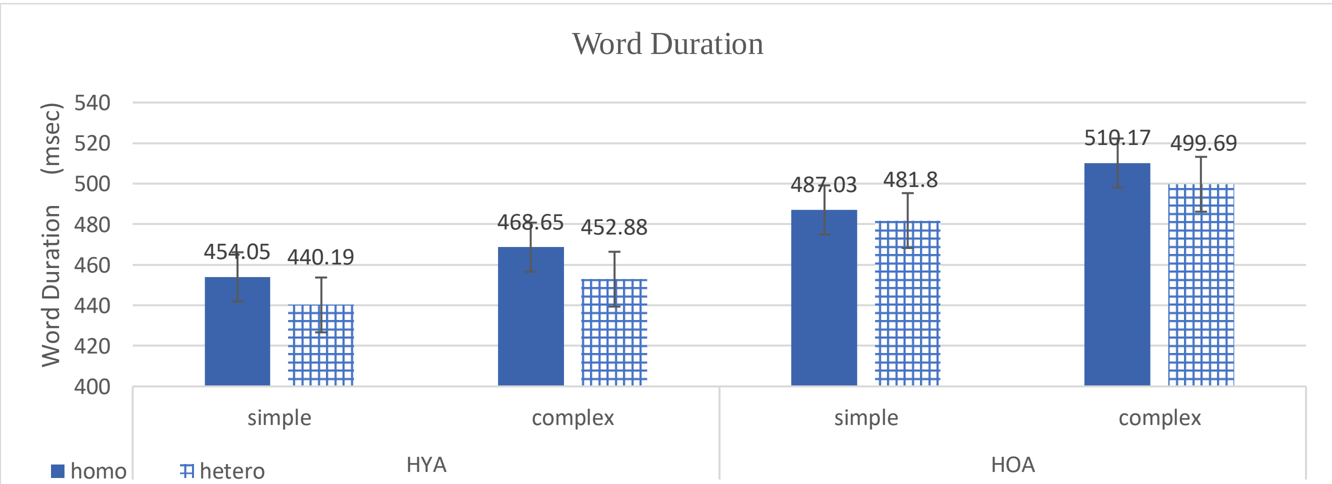


Figure 2.5 Mean WD by context (homogenous and heterogeneous) and complexity for each group (healthy younger and older adults). Error bars represent the standard error of the mean.

Table 2.8: *Results of the Statistical Analysis for the Healthy Younger and Healthy Older Adults on the Picture-naming Task*

	Between Group Analysis	
	Condition	**Statistics Analysis**
Accuracy	Group	(F (1,59) =32.861, η^{2}= .994, p< .000)
	Semantic blocking	(F (1,59) =.092, η^{2}= .018, p= .300)
	Articulatory complexity	(F (1,59) =5.932, η^{2}= .091 p< .019)
	Blocking x Complexity	(F (1,59) =1.593, η^{2}= .026, p= .218)
	Blocking x Group	(F (1,59) =.004, η^{2}= .000, p= .948)
	Complexity x Group	(F (1,59) =.601, η^{2}= .011, p= .442)
	Blocking x Complexity x Group	(F (1,59) =.589, η^{2}= .010, p= .446)
Reaction Time (ms.)	Group	(F (1.56)= 20.95, η^{2}=.437, p< .000)
	Semantic blocking	(F (1.56)= 28.894, η^{2}= .335, p< .000)
	Articulatory complexity	(F (1.56)= 71.551, η^{2}= .552, p< .000)
	Blocking x Complexity	(F (1.56)= .449, η^{2}= .008, p= .505)
	Blocking x Group	(F (1.56)= 1.422, η^{2}= .024, p=.238)
	Complexity x Group	(F (1.56)= 4.928, η^{2}= .780, p< .030)
	Blocking x Complexity x Group	(F (1.56)= 2.232, η^{2}= .037, p= .141)
Word Duration (ms.)	Group	(F (1.56)= 109.250, η^{2}= .802, p< .000)
	Semantic blocking	(F (1.56)= 39.861, η^{2}= .407, p< .000)
	Articulatory complexity	(F (1.56)= 73.491, η^{2}= .568, p< .000)
	Blocking x Complexity	(F (1.56)= 1.433, η^{2}= .025 p= .236)
	Blocking x Group	(F (1.56)= 3.754, η^{2}= .061, p= .056)
	Complexity x Group	(F (1.56)= .305, η^{2}= .005, p= .583)
	Blocking x Complexity x Group	(F (1.56)= 3.268, η^{2}= .053, p= .076)

2.6.1 Analysis of Accuracy

The between group ANOVA analysis revealed a main effect of Group (F (1,59) =32.861, η^{2}= .994, p< .000), that is overall HYA had higher accuracy scores in total ($M_{accuracy}$= 176.7, $SD_{accuracy}$= 14.17, percentage= 88%) as compared to the HOA ($M_{accuracy}$= 167.76, $SD_{accuracy}$= 18.41, percentage= 83%). Additionally, there was a main effect of

Articulatory Complexity (F (1,59) =5.932, $\eta^{2=}$ .091 $p< .019$) where more errors were produced when words were complex ($M_{complex}$= 85.27, $SD_{complex}$= 9.26) as compared to simple (M_{simple}= 86.76 , SD_{simple}= 8.34). As is depicted in Table 2.8 above, no effect of Semantic Blocking or two-way and three-way interactions for accuracy.

2.6.2 Analysis of Reaction Time

A between subjects ANOVA analysis revealed a main effect of Group (F (1.56)= 20.95, $\eta^{2=}$ .437, $p< .000$), where HYA RT's (M_{RT} = 693.35, SD= 62.87) were 79 ms shorter than those of the HOA (M_{RT} = 772.62, SD= 68.89). A main effect of Blocking (F (1,56) = 28.89, $\eta^{2=}$ .335, $p< .000$) was also observed. Reaction times for the stimuli named in the heterogeneous conditions (M_{hetero}= 720.58, SD_{hetero}= 78.18) were 21 ms shorter than the RT for the naming of stimuli in homogenous conditions (M_{homo}= 741.45, SD_{homo}=601.07). A main effect of Complexity (F (1,33) =71.551, $\eta^{2=}$ .552, $p< .000$) was also found with RT for simple words being 29 ms shorter (M_{simple}= 718.60, SD_{simple}= 72.84) than the complex words ($M_{complex}$= 747.58, $SD_{complex}$= 82.74). The main effects can be seen in Figure 2.5 above.

A two-way interaction was shown between Complexity and Group (F (1,56) = 4.928, $\eta^{2=}$ .078, $p< .030$). As observed by the further analysis from the one way within group ANOVA, RT's were significantly longer (39 ms longer) on complex words as compared to simple words for the HOA (F (1,29) = 46.169, $\eta^{2=}$ .614, $p< .000$; M_{simple}= 752.25, SD_{simple}= 65.46; $M_{complex}$ = 791.27, $SD_{complex}$ = 75.68). This difference is significant but not as profound in the HYA (F (1,29) =25.439, $\eta^{2=}$ .467, $p< .000$; M_{simple}=682.72, SD_{simple}= 61.98; $M_{complex}$ = 791.27, $SD_{complex}$ = 75.68). The interaction can be seen in the Figure 2.6 below.

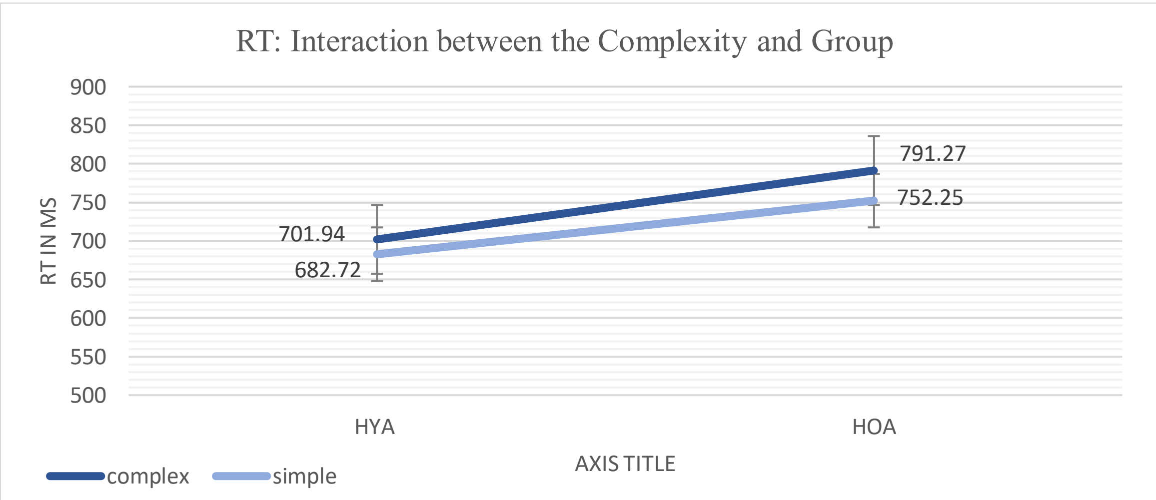


Figure 2.6 Interaction between the articulatory Complexity and Group for the reaction time analysis.

2.6.3 Analysis of Word Duration

The between subject's ANOVA analysis revealed a Group effect (F (1,56) =109.250, $\eta^{2=}$ .802, *p*< .000), specifically, overall HYA WD were 40 ms shorter (M_{WD}= 494.57, SD= 42.65) compared to the HOA (M_{WD}= 454.02, SD= 45.60). A main effect of Blocking (F (1,56) =39.86, $\eta^{2=}$ .407, *p*< .000) was also indicated. That is, WD were in the homogenous conditions were 13 ms longer (M_{homo}= 479.91, SD_{homo}= 47.52) as compared to the heterogeneous condition (M_{hetero}= 466.69, SD_{hetero}= 50.13).

Additionally, a main effect of Complexity (F (1,56) =73.491, $\eta^{2=}$.568, *p*< .000) was found in that complex words took an average of 18 ms longer to articulate ($M_{complex}$= 482.94, $SD_{complex}$= 50.52) compared to the words that were considered simple (M_{simple}= 464.12, SD_{simple}= 47.36).

2.6.4 Repetition Control Task Results

As indicated in Table 2.9 below, a main effect of group was found in all three variables, where HOA made more errors and displayed longer reaction times and word durations than the HYA. Additionally, a main effect of articulatory complexity and an interaction between Complexity and group was exhibited in the word duration measures as HOA exhibited longer WD than HYA on complex words, as they are frequently considered longer than those of the simpler ones.

Table 2.9: *Main effects and interactions for the healthy younger and healthy older adults on the repetition control task*

Naming statistical analysis		*Repetition statistical analysis*	
		Accuracy	
Group	F (1,56) =.86.3.91, $\eta^{2=}$ .994, p< .000)	Group	F (1, 56) = 8.141, n^{2}= .999, p< .000
Semantic blocking	F (1,56) =.1.092, $\eta^{2=}$ .018, p=.300	Semantic blocking	F (1.56) = 3.538, $\eta^{2=}$ .057, p= .065
Articulatory complexity	(F (1,56) =5.932, $\eta^{2=}$ .091 p< .019	Articulatory complexity	F (1.56)= 73.491, $\eta^{2=}$ .008, p=.114
Blocking x Complexity	F (1,56) =1.593, $\eta^{2=}$ .026, p= .218	Blocking x Complexity	F (1.56)= .397, $\eta^{2=}$ .007, p= .531
Blocking x Group	F (1,56) =004, $\eta^{2=}$ .000, p= .948	Blocking x Group	F (1.56) = 5.285, $\eta^{2=}$ .057, p= .084
Complexity x Group	F (1,56) =.601, $\eta^{2=}$ .011, p= .442	Complexity x Group	F (1.56)= .305, $\eta^{2=}$ .005, p= .583
Blocking x Complexity x Group	F (1,56) =.589, $\eta^{2=}$ .010, p= .446	Blocking x Complexity x Group	F (1.56)= 1.102, $\eta^{2=}$ .019, p= .298
		Reaction Time (ms.)	
Group	F (1.56)= 20.95, $\eta^{2=}$ .437, p< .000	Group	F (1.56)= 7.274, $\eta^{2=}$ .984, p< .000
Semantic blocking	F (1.56)= 28.894, $\eta^{2=}$ .3353, p< .000	Semantic blocking	F (1.56)= 2.211, $\eta^{2=}$ .037, p= .142
Articulatory complexity	F (1.56)= 71.551, $\eta^{2=}$ .552, p< .000	Articulatory complexity	F (1.56)= 868.784, $\eta^{2=}$ 000, p= .937
Blocking x Complexity	F (1.56)= .449, $\eta^{2=}$ .008, p=.505	Blocking x Complexity	F (1.56)= .002, $\eta^{2=}$ .000 ,p= .967
Blocking x Group	F (1.56)= 1.422, $\eta^{2=}$ .024, p= .238	Blocking x Group	F (1.56)= .305, $\eta^{2=}$ .005, p= .583
Complexity x Group	F (1.56)= 4.928, $\eta^{2=}$ .780, p< .030	Complexity x Group	F (1.56)= .456, $\eta^{2=}$ .008, p= .502
Blocking x Complexity x Group	F (1.56)= 2.232, $\eta^{2=}$ .037, p= .141	Blocking x Complexity x Group	F (1.56)= 2.871, $\eta^{2=}$ .047, p=..096
		Word Duration (ms.)	
Group	F (1.56)= 109.250, $\eta^{2=}$ .802, p< .000	Group	F (1.56)= 6.981, $\eta^{2=}$ .988, p< .000
Semantic blocking	F (1.56)= 39.861, $\eta^{2=}$ .407, p< .000	Semantic blocking	F (1.56)= 3.709, $\eta^{2=}$ .060, p= .059
Articulatory complexity	F (1.56)= 73.491, $\eta^{2=}$ .568, p< .000	Articulatory complexity	F (1.56)= 24.963, $\eta^{2=}$ .301, p< .000
Blocking x Complexity	F (1.56)= 1.433, $\eta^{2=}$ .025 p= .236	Blocking x Complexity	F (1.56)= 6.671, $\eta^{2=}$ .012, p=.103
Blocking x Group	F (1.56)= 3.754, $\eta^{2=}$ .061, p= .058	Blocking x Group	F (1.56)= .305, $\eta^{2=}$ .3.492, p= .067
Complexity x Group	F (1.56)= .305, $\eta^{2=}$ .005, p= .583	Complexity x Group	F (1.56)= 27.615, $\eta^{2=}$ .323, p< .000
Blocking x Complexity x Group	F (1.56)= 3.268, $\eta^{2=}$ .053, p= .076	Blocking x Complexity x Group	F (1.56)= 1.447, $\eta^{2=}$ .024, p= .234

2.7 Discussion

The purpose of the current study was to examine the interaction between linguistic and speech motor processes in healthy younger and healthy older adults. The use of a wide range of variables – accuracy, RT's, and WD's were implemented to measure the interaction of linguistic and speech motor processes on a picture-naming task using stimuli in different semantic contexts (homogenous vs heterogeneous) with varying articulatory complexity (simple vs complex). An overall summary for the main findings for all three variables can be seen in Table 2.10 below.

Table 2.10: *Overall Summary of the Results of the Current Study on HYA and HOA*

	Parameters	Findings	η^{2}=	p
Accuracy	Group	✓	.994	<.000
	Semantic blocking	X	.018	.300
	Articulatory complexity	✓ (Si > Co)	.983	<.019
	Blocking x Complexity	X	.026	.218
	Blocking x Group	X	.000	.948
	Complexity x Group	X	.011	.442
	Blocking x Complexity x Group	X	.010	.448
RT				
	Group	✓	.437	<.000
	Semantic blocking	✓ (Ho > Ht)	.335	<.000
	Articulatory complexity	✓ (Co > Si)	.552	<.000
	Blocking x Complexity	X	.008	.505
	Blocking x Group	X	.024	.238
	Complexity x Group	✓ HOA (Co+ Si> HYA (Co+Si)	.780	<.030
	Blocking x Complexity x Group	X	.037	.141
WD				
	Group	✓	.802	<.000
	Semantic blocking	✓ (Ho > Ht)	.407	<.000
	Articulatory complexity	✓ (Co > Si)	.568	<.000
	Blocking x Complexity	X	.025	.236
	Blocking x Group	X	.061	.058
	Complexity x Group	X	.005	.583
	Blocking x Complexity x Group	X	.053	.076

Note: ✓- significant finding, X- insignificant finding, Si- simple, Co- complex, Ho- homogenous, Ht- heterogeneous

2.7.1 Effect of Ageing

In line with our predictions, the HOA participants were significantly affected by the manipulations of both the linguistic and speech motor processes. The manipulations of these processes instigated a reduction in naming accuracy, longer RT, and longer WD in comparison to HYA. Studies utilising the semantic blocked naming paradigm have provided evidence that older adults have progressively more difficulty and exhibit longer reaction times as lexical and semantic demands increase (i.e., in homogenous conditions), as opposed to the younger participants (Belke & Meyer, 2007; Britt et al., 2016). In a study by Connor et al. (2004) it was revealed that there was a significant effect of age, where age increased the difficulty of word retrieval, causing the older participants to have an increase in errors and an increase in response RT's to picture-naming. Furthermore, Tsang and Lee (2003), utilised a picture-naming task to measure the effects of ageing on linguistic processing - their findings indicated that normal ageing influenced lexical access where younger adults performed much better than older adults in terms of accuracy as well as RT's. Corresponding to our results, Britt et al. (2016) investigated the effect of ageing on linguistic processing on 20 healthy younger and 20 older education-matched adults in a picture-naming task. Results indicated that in addition to a main effect of age (slower picture-naming for older adults compared to younger adults), older adults exhibited lower accuracy scores and were slower to name pictures overall, with age-related differences increasing as selection demands increased. Additionally, the results of this study revealed that although both groups of participants, HYA and HOA, exhibited longer RT on the articulatory complex words, indicative that the semantic interference caused by the semantic blocking influences speech motor processes, the HOA were affected to a higher degree.

In regard to WD, the HOA exhibited longer WD overall as compared to the HYA. Consistent with our results, previous literature has provided evidence of age-related slowing in picture-naming, where older adults are slower in picture-naming as compared to younger adults (Cotelli et al., 2010; Morrison et al., 2006; Morrison et al., 2008). Furthermore, Belke & Meyer (2007), used a confrontational naming task where it was evident that the older adults articulated the object names significantly slower and paused more often than the younger adults.

The results from our study as well as previous studies support our initial hypothesis that healthy older adults exhibit progressively more difficulty in lexical processing (reaction time) and articulation (word duration) as linguistic and speech motor demands increase (La Grone & Spieler, 2006; Mortensen et al., 2006).

2.7.2 Manipulations of Linguistic Processes (Semantic Contexts)

The manipulation of linguistic variables in our study, specifically the semantic context, was manifested in longer RT's for words in the semantically blocked (homogenous) conditions. This finding is supported by previous and current literature on lexical access. Empirical literature has provided sufficient evidence that the manipulation of linguistic variables such as semantic contexts and phonological complexity directly affect linguistic processing, as evidenced by a decrease in accuracy and longer reaction times (Belke et al., 2005; Damian and Als, 2005; Harvey & Schnur, 2016). Further corroborating our results, Verhaegen & Poncelet (2012) investigated RT differences in healthy younger and healthy older adults during picture-naming: results of their study indicated that both groups of participants exhibited longer RT on the words in the semantically blocked (homogenous) conditions.

The previously discussed results of our study provide additional data to the existing literature on ageing, lexical access, and linguistic processing. However, our results also indicated that manipulations of linguistic processes at the semantic level influenced speech motor performance where WD's were longer on the words in the semantically blocked contexts. This finding is distinctive and substantiates the influence linguistic and speech motor processes have on one another. To elaborate, most models of spoken word production agree that word production involves a number of processing stages, namely at a conceptual level, a lexical-semantic level, and a phonological-speech motor preparation level (Dell, 1986; Levelt et al., 1999). Those models also generally agree that during the lexical access of a target word (e.g., *dog*) semantically related words are simultaneously activated as competitors (e.g., *cat, wolf, tiger*) (Dell, 1986; Caramazza, 1997; Levelt et al., 1999; Goldrick & Rapp, 2002; Indefrey, 2011). Numerous studies investigating word production and lexical access have found that the activated competitors from the same semantic category (e.g., '*cat, wolf, tiger'* as competitors for the targeted word '*dog'*) cause naming reaction times to become longer. This increase in naming reaction time is also known as the semantic interference effect (Glaser & Dungelhoff, 1984).

Congruently, previous research utilising picture-naming experiments with manipulations of the semantic contexts typically show that repeated access to the same semantic category induces a semantic interference effect. This interference is thought to arise during the selection of a target entry from among co-activated semantically related lexical entries (Abdel Rahman & Melinger, 2011; Belke, 2008; Schnur, Schwartz, Brecher, & Hodgson, 2006). Importantly, previous research assumes that the semantic interference effect is situated at the lexical level. However, the results of our study substantiate the idea that the effect of semantic interference extends beyond linguistic levels of word production and influences the articulatory durations of the targeted word and speech motor performance.

Additionally, word production models fall into two distinct categories in regards to lexical access, discrete and cascaded. The discrete two-step models assume that speaking proceeds in a serial manner from semantic to phonological retrieval and that the two stages are largely disconnected from each other with no feedback to higher level processes from lower levels (Levelt et al., 1999). In contrast, cascaded (Humphreys, Riddoch, & Quinlan, 1988) or interactive (Dell, 1986; Dell & O'Seaghdha, 1991; Harley, 1993) speech production models assume that all activated lexical-semantic representations affect phonological processing by spreading a proportional amount of activation to their corresponding phonological segments. Moreover, those models presume that the activation of the phonological word form occurs before the lexical selection takes place (cascaded processes), and the information from the sub-lexical level affects the higher levels of processing. The results of our study are indicative that the effects exhibited in speech motor execution are mediated by the cascading influences from the manipulations of linguistic variables.

2.7.3 Manipulation of Speech Motor Processes (Articulatory Complexity)

Furthermore, manipulations of speech motor processes, specifically articulatory complexity, induced a decrease in naming accuracy and an increase in WD's. That is, accuracy of naming decreased and WD were longer on articulatory complex words as compared to the simple ones. It is vital to recognise that the complex words (e.g., axe, lock, lips) used in our study were not always longer in length than the simple words (e.g., turkey, tomato, window) yet they required longer WD's. Similar to our results, Wright (1997, 2004), Munson and Solomon (2004), and Munson (2007) investigated the effects of words with varying vowel complexity on articulation on healthy adults to find that words with vowels in dense neighbourhoods embedded within them were considered 'complex words' and were hyper-articulated compared to words with vowels in sparse neighbourhoods, or 'simple words'.

Additionally, in line with our results, recent studies by Sadagopan and Smith (2013) and Bilodeau- Mercure et al. (2015) examined the effects of word length and articulatory complexity in a repetition task on accuracy, lip coordination, and production duration on healthy adults. The researchers reported a decrease in accuracy and longer production durations on the repetition of longer complex words. Therefore, it is evident from our results and previous results from studies on this topic, that the manipulation of the articulatory complexity of words decreases naming/repetition accuracy and affects articulatory execution.

Perhaps the most striking finding of the present study was that the manipulation of the articulatory complexity of words directly affected linguistic processing, where participants in this study demonstrated an increase in RT on complex words as compared to the simple ones. That is, words that were considered articulatory complex required longer RT during naming. This result is indicative of the possibility that manipulations within the speech motor system may reshape the processing of the linguistic system. Additionally, these results may provide support for the notion that specifications for speech motor execution of word production are not completely independent of lexical information. Essentially, our findings suggest that the process of linguistic planning is directly influenced by articulatory variables. Articulatory complex words possibly require an increased amount of time for lexical planning, phonological encoding, and for speech motor preparations compared to the simple words (Howell, 2011). In this study, linguistic processes were influenced, as evidenced by the longer RT, by the changes of speech motor properties such as articulatory complexity. This implies that speech motor performance does not occur independently or subsequent to linguistic processes, but rather that there is a cascading of information between the two processes.

The link between the linguistic processing, lexical-semantic processes, phonological processing, and speech motor control continues to play an important theoretical role in our understanding of speech production. As discussed previously, the aspects of spoken word production can be divided into three main stages; first, the process of planning (lexical, semantic, and phonological retrieval processes); second, the motor preparation; and lastly, the speech motor execution of the plan (articulation). Linguistic processing is generally argued to be at a higher level than speech motor processing with a unidirectional flow from language to movement (Levelt et al., 1999). However, the results of our study demonstrate that manipulation of speech motor processes directly affect linguistic processing, validating the possibility that linguistic and speech motor processes may occur in parallel to one another and involve bidirectional interactive activation.

2.7.4 Conclusion

To conclude, the present study provides empirical evidence of the influence of linguistic and speech motor processes on one another. Manipulations of the linguistic processes directly affected the speech motor processes, and manipulations of the speech motor processes influenced linguistic processing. Similar postulations of the interaction between linguistic and speech motor execution are becoming increasingly frequent in psycholinguistic research in healthy and impaired populations (Arnold, 2008; Balota et al., 1989; Bard et al., 2000; Bell et al., 2009; Kahn & Arnold, 2012, 2015; Lam & Watson, 2010; MacDonald, 2013; Watson et al., 2015). Additionally, the results of this study demonstrated the decline in the planning and execution of speech production in HOA. Specifically, the results of this study confirm that ageing negatively impacts lexical access accuracy and speed as well as speech motor control.

Taken together, the results of this study provide additional support for the 'cascading' models of spoken word production, in which the manipulation of input at the lexical level leads to increased changes at the speech motor level (Goldrick & Blumstein, 2006; Permunage, Blumstein, Myers, Goldrick & Baese- Berk, 2011). These results do not support any one particular model over another; however, they do provide further support for an interaction between lexical and speech motor processes.

Chapter 3

Measuring the Influence of Linguistic and Speech Motor Processes during Picture Naming in Aphasia

3.1 Abstract

Background:

As highlighted in Chapter 1, despite the significance of linguistic and speech motor processes on word production, there are a limited number of studies that have investigated the influence of linguistic and speech motor processes on one another in people with aphasia. Although, it has been well-established in the literature that reduced verbal output in the people with aphasia could be due to influence of the concomitant impaired speech motor function. In this research, we investigate the interaction of lexical processes (through the manipulation of semantic activation by using the non-cyclical blocked picture naming paradigm) and articulatory complexity (by varying the phonetic complexity of the words) in people with aphasia and healthy controls.

Aims:

This research had three aims: 1. To determine if there are differences in word production accuracy, RT, and WD when PWA and HC named pictures with varying articulatory complexity (simple vs complex) in semantically homogenous/heterogeneous conditions. 2. To determine if the interaction between semantic blocking and articulatory complexity (or lack of it) depend on participant characteristics (i.e., fluent vs non-fluent) in people with aphasia. 3. To determine if the influence of linguistic and speech motor processes depend on the individual participant characteristics in people with aphasia.

Methods:

Participants were 17 people with aphasia (Mean= 67.47, SD= 9.94) and 17 age- and education-matched healthy adults (Mean= 63.29, SD= 11.06). Similar to Chapter 2, the investigation implemented a non-cyclical blocked naming paradigm where participants were required to name a series of 100 black and white pictures depicting nouns in two semantic contexts: homogenous and heterogeneous with 10 sets in each context. Each set was constructed in such a way to include 10 exemplars with 5 of them being considered as phonetically simple and the other 5 as phonetically complex based on the Index of Phonetic Complexity. Variables that were of interest were accuracy, RT to measure word processing, and WD to measure speech motor function.

Results:

People with aphasia demonstrated lower accuracy scores, longer RT, and longer WD as compared to the healthy controls. Similar to findings from Chapter 2, semantic blocking variation resulted in predicted increase in RT, increased WD in homogeneous condition, as well as interactions of Group with both RT and WD. Compared to HC, semantic blocking resulted in significantly longer RT and WD in PWA. Articulatory complexity variation also resulted in increased RT and increased WD for complex words. Articulatory complexity also demonstrated interactions with Group for both RT and WD, such that, compared to the healthy control, the participants with aphasia showed significantly longer RT and WD for complex words. Importantly, we also found a three-way interaction amongst Group, Blocking and Articulatory complexity. The comparison of fluent vs. non-fluent groups across the manipulations, yielded stronger and more prevalent number of effects (i.e., they were more affected by semantic blocking and articulatory complexity) for the non-fluent PWA.

Conclusions & Implications:

The most significant finding of this study is the demonstration that variation in the semantic activations as achieved by blocked picture naming and variation of articulatory complexity has a clear and detectable influence on the speech motor performances. Importantly, this effect is differentially affected between PWA and HC. Our results highlight the importance of including the notion of interaction in theoretical models of word production, especially at the level of articulatory implementation. These findings will have significant clinical implications as it helps us to think beyond accuracy and RT.

3.2 Introduction

Aphasia is usually defined as an impairment of language, affecting the production and comprehension of speech and the ability to read or write (McNeil & Pratt, 2001). These definitions presume that the impairment caused by aphasia is purely linguistic, disregarding how speech motor deficits could exacerbate the symptoms of aphasia. Current literature has identified the significance of the co-existence of speech motor deficits and aphasia, as well as mentioned the significant probability that the reduced verbal output and telegraphic speech in individuals with aphasia is actually the manifestation of that co-existence (J. Duffy, 2016). Other research has recognised that most individuals with fluent and non-fluent aphasia exhibit noticeable speech motor problems, but to varying degrees (J. F. Blumstein, 2001; S. E. Blumstein, 1998; Cannito, Strauss Hough, Dressler, & Buder, 2013; M. R. McNeil & Kent, 1990; Scholl et al., 2018; Van Lieshout, Bose, Square, & Steele, 2007). Unfortunately, in the study of word production in aphasia, most research has limited itself to impairments of linguistic and phonological processing while neglecting the motor aspects of speech production (Bose et al., 2007; Lee et al., 2015).

3.2.1 Linguistic Deficits in People with Aphasia

In people with aphasia, multiple linguistic aspects (i.e., semantics, phonology, morphology, syntax) are impaired - each to varying degrees. Aphasia falls into a range of diverse classifications: the language impairment can be severe to the point where the patients' ability to communicate is almost impossible, or it can be very mild, affecting only a single aspect of language use such as the ability to retrieve the names of objects.

The processing of semantic aspects of a word's representation is customarily affected to varying degrees in people with aphasia, depending on the aphasia classification and severity level (Hillis & Caramazza, 1995; Ralph, Moriarty, & Sage, 2002). In people with aphasia, semantic knowledge is typically preserved but the impairment in the semantic access prevents the effective retrieval of the information (Lambon Ralph, 2014). The semantic impairments are manifested in difficulties in mapping sensory perception onto semantic knowledge (Thompson, Robson, Lambon Ralph, & Jefferies, 2015), impairments in the selection and retrieval of semantic knowledge (Hillis & Caramazza, 1995; Jefferies & Lambon Ralph, 2006), and impairments in matching semantically associated concepts (Corbett, Jefferies, Ehsan, & Lambon Ralph, 2009; Jefferies & Lambon Ralph, 2006).

It is also agreed that both fluent and non-fluent people with aphasia produce phonological errors in their speech (Kurowski & Blumstein, 2016). These errors often involve phoneme substitution (e.g., 'comsuter' for computer), phoneme omission (e.g., 'comuter' for computer), phoneme addition (e.g.,'comsputer' for computer), or the incorrect sequencing of one or more phonemes within a word. Similar patterns of errors are found in both the fluent and non-fluent people with aphasia. Phoneme substitution errors are considered the most common error type, maintaining more errors with consonants than vowels, and more single substitutions than multiple substitutions (S. Blumstein, 1973; Burns & Canter, 1977; Haley, Jacks, & Cunningham, 2013; Scholl et al., 2018). Furthermore, many people with aphasia, regardless of classification, exhibit difficulty retrieving verbs and nouns whether in single word production or in sentences (Berndt, Mitchum, Haendiges, & Sandson, 1997; Kohn, Lorch, & Pearson, 1989; Williams & Canter, 1987). This is supported by studies showing that people with non-fluent aphasia tend to have more difficulty in verb retrieval while people with fluent aphasias have greater difficulty retrieving nouns (Bates, Chen, Tzeng, Li, & Opie, 1991; Kambanaros, 2010; Luzzatti et al., 2002)

Additionally, sentence comprehension and sentence production are often impaired in people with aphasia, different impairment patterns being associated with the different classifications of aphasia. Innumerable research studies have asserted that sentences with a non-canonical word order such as passives and object relative clauses (e.g., the girl was kissed by the boy) are considered more difficult for people with aphasia to produce than the sentences with a canonical order made up of a agent, verb, and theme (e.g, I like milk). This difficulty in producing non-canonical sentences as compared to canonical sentences has been well documented in both fluent and non-fluent people with aphasia for both sentence production (Edwards, 2002; Faroqi-Shah & Thompson, 2003; Rochon, Laird, Bose, & Scofield, 2005) and comprehension (Bastiaanse & Edwards, 2004; Berndt, Mitchum, & Haendiges, 1996; Caramazza & Zurif, 1976; Cho-Reyes, Mack, & Thompson, 2016).

Nevertheless, there are virtually no people with aphasia who seem to have a selective deficit in only one component of language with the remainder of the linguistic system intact.

Although Broca's aphasia is typically characterised by agrammatism, patients may also exhibit semantic impairment as well as phonetic and phonological deficits (Goodglass, 1968; Kurowski & Blumstein, 2016). Similarly, people with Wernicke's aphasia typically exhibit an impairment in phonological processing, while syntactic and semantic deficits are also evident in both comprehension and production of words (Faroqi-Shah & Thompson, 2003; Thompson et al., 2015).

Nonetheless, while aphasia is primarily characterised by disturbance of linguistic functions, people with aphasia have been observed to also exhibit impairments in motor speech (Vijayan & Gandour, 1995). The interaction between linguistic and speech motor processes is increasingly gaining traction in psycholinguistic research, as recent studies on healthy and impaired individuals have demonstrated that factors which influence linguistic processes (e.g., utterance length) can also affect the speech motor properties of the word which is eventually produced (Cannito et al., 2013; Lee et al., 2015).

3.2.2 Speech Motor Deficits in People with Aphasia

In the area of neurolinguistics, the association between linguistic and speech motor functions is vital in developing our understanding of speech production in aphasia, as people with aphasia exhibit impairments in both linguistic and speech motor functions. However, its nature remains poorly understood, as the traditional views of aphasia assume that it is purely linguistic and disregard the potential impact of the speech motor deficits (Kahn & Arnold, 2015; McNeil & Kent, 1990). In addition to the prominent deficits in linguistic processing in people with aphasia, it has been reported that articulatory processing is compromised, albeit to varying degrees in both fluent and non-fluent aphasia (Kurowski & Blumstein, 2016; Kurowski, Hazen, & Blumstein, 2003; Vijayan & Gandour, 1995).

The speech motor impairment in individuals with non-fluent aphasia is clearly evident, especially in individuals with Broca's aphasia. The speech impairment is characterised by perceptual features such as reduced movement of the articulators, reduced rate of speech, distortions, substitutions, and additions of speech sounds, articulatory groping, and irregular prosodic patterns (S. E. Blumstein, 1990, 1998; McNeil & Kent, 1990). The impairment also manifests itself in difficulties with voicing (S. E. Blumstein, Baker, & Goodglass, 1977; S. E. Blumstein, Cooper, Goodglass, Statlender, & Gottlieb, 1980; Kurowski et al., 2003), speech sound errors (Nespoulous et al., 2013), and phonemic paraphasia (S. Blumstein, 1973; Haley et al., 2013).

On the other hand, current and previous research investigating speech production in aphasia has revealed that speech motor deficits are also apparent in individuals with fluent aphasia, though these are often subtle (Balan & Gandour, 1999; Baum et al., 1990; Seddoh, 2004, 2008; Vijayan & Gandour, 1995). Due to these deficits being difficult to observe clinically, as they only emerge under fine acoustic and kinematic analysis, they are considered subclinical. The speech motor impairment in people with fluent aphasia is manifested by an increase in the variability of the implementation of numerous phonetic parameters (R. Kent & McNeil, 1987; M. R. McNeil & Kent, 1990; M. R. McNeil, Robin, & Schmidt, 2009; Seddoh, 2004), abnormal patterns of temporal control of segmental structure within and between words (Baum, 1992; Baum & Boyczuk; 1999), articulatory implementation deficits (Baum et al., 1990; Cannito et al., 2013), vowel formant frequencies, and vowel duration (Gandour et al., 1992; Ryalls, 1986; Tuller, 1984).

In addition to lexical and speech motor impairments, apraxia of speech often co-exists in people with aphasia (Duffy, Strand, & Josephs, 2014). Apraxia of speech is a motor speech disorder which manifests itself in articulatory deficits. Both apraxia of speech and aphasia are associated with left hemisphere cerebral vascular injuries, and their comorbidity is high with a strong correlation between the severity of aphasia and apraxia (Kobayashi & Ugawa, 2013; Papagno, Della Sala, & Basso, 1993). There is a robust amount of literature which has explored the association between apraxia of speech and aphasia, confirming the invariable co-occurrence of apraxia in individuals with non-fluent aphasia as well as the existence of apraxia in individuals with fluent aphasia (Cannito et al., 2013). It has been estimated that the co-occurrence of apraxia of speech with non-fluent aphasia is more than 80%, with it being indistinguishable in individuals with Broca’s aphasia (J. Duffy, 2016; Odell, McNeil, Rosenbek, & Hunter, 1991). Likewise, speech errors indicative of motor programming deficiencies such as phonetic distortions, articulatory groping, dysfluency, and articulatory errors have been reported in people with fluent aphasia, though to a lesser extent (Cannito et al., 2013; McNeil, Odell, Miller, & Hunter, 1995; McNeil et al., 2009; Odell et al., 1991).

To conclude, difficulty in naming is a universal feature in people with aphasia. Current and previous literature has indicated the involvement and synchronisation of conceptual, semantic, phonological, and articulatory processes for precise and accurate naming production. People with aphasia exhibit deficits in linguistic processes (i.e., conceptual, semantic, phonological) as well as speech motor production deficits (i.e., articulation), without many attempts in the literature to combine the two. Data from neurophysiological, neurological, behavioural, and acoustic investigations strongly confirm the interaction between lexical and articulatory processes, which can be observed in various disorders beyond aphasia (Bose & van Lieshout, 2008; Bose et al., 2007; Kent & McNeil, 1987; M. R. McNeil & Kent, 1990; Scholl et al., 2018). Therefore, it is imperative to understand the possible implications of the impairments in linguistic and speech motor processes and the influence of those impairments on naming. In this research, we will investigate the interaction of lexical processes (specifically semantics) and speech motor function (specifically articulation).

3.2.3 Interaction of Linguistic and Speech Motor Processes in with Aphasia

The interaction of linguistic and speech motor processes in people with aphasia has been studied extensively using behavioural, kinematic, acoustic, and functional neurological methodologies. As discussed above, it is evident that people with aphasia exhibit impairments in lexical and speech motor processes (e.g. Kurowski & Blumstein, 2016; Nespoulous et al., 2013). The impact of speech motor impairment on lexical access in people with aphasia has recently garnered interest and research has shown that the lexical impairment in people with aphasia is modulated by linguistic factors such as word frequency, semantic context, and articulatory complexity (Bose et al., 2007, 2011).

The behavioural studies that were discussed in detail in Chapter 1 have demonstrated that the linguistic characteristics of the targeted stimuli, such as word length, frequency, and syntactic structure, have a direct influence on the speech output of people with aphasia. Results of previous studies have shown that as the argument structure of a verb increases in complexity (i.e., as the number of arguments associated with the verb increases) so does the difficulty in the speech motor production (Bastiaanse & Edwards, 2004; De Bleser & Kauschke, 2003; Kim & Thompson, 2000; Luzzatti et al., 2002). Behavioural studies measuring accuracy and reaction time in people with aphasia during picture-naming have reported that words with many phonological neighbors were less error-prone and faster to name (Goldrick et al., 2010; Gordon, 2002) and words with a high name agreement produced shorter gaze duration and higher accuracy in naming (Lee et al., 2015).

Kinematic studies investigating articulatory timing and coordination in speech production on people with aphasia have provided evidence of the influence of utterance length and rate on speech movement kinematics (Bose & van Lieshout, 2008, Bose & van Lieshout, 2012; Itoh & Sasanuma, 1987; McNeil & Kent, 1990). The findings of those studies have indicated that manipulation of experimental properties (utterance length, rate of speech) on lexical variables (phonemes, words, and sentences) effected changes in speech movement execution, peak velocity, amplitude, and lip kinematics, while displaying a decrease in movement and movement duration (Bose & van Lieshout, 2008; Bose & van Lieshout, 2012).

Additionally, functional neurological studies have provided empirical evidence for the interaction between linguistic and speech motor processes in the dual activation of both speech and motor areas during the silent reading of action words (de Lafuente & Romo, 2004; Hauk, Johnsrude, & Pulvermuller, 2004). These found that lexical retrieval improved when motor areas were activated through transcranial magnetic stimulation during picture-naming (Harnish et al., 2011; Meinzer et al., 2011a; Benjamin et al., 2014), and fluency of speech improved when the transcranial magnetic stimulation in motor areas was integrated with speech language therapy for people with aphasia (Marangolo et al., 2014; Marangolo, Fiori, Calpagnano, et al., 2013).

In conclusion, it is evident that linguistic variables have a direct influence on the speech motor processes of people with aphasia. It is also evident that articulatory complexity has a direct impact on phoneme production and reading words out loud but there remains the empirical question of whether this is the case for word-naming, which is a consistent difficulty across patients with aphasia.

3.3 The Current Investigation, Research Questions, and Predictions

The present study examined the interaction of linguistic and speech control processes in picture-naming between 17 people with aphasia (PWA, hereafter) and 17 age- and education-matched healthy control participants (HC, hereafter). The participants in group PWA were characterised by semantic, phonological, and speech motor skills. We collected data on all participants during a picture-naming task incorporating the semantic blocked non-cyclical picture-naming paradigm with items varying in articulatory complexity. The same tasks used in Chapter 2 were replicated in this chapter with a minor increase in picture display time from 1.5 second to 5 seconds in the picture-naming task. The analysis investigated the effect of semantic context (homogenous vs heterogeneous) and the effect of articulatory complexity (simple vs complex) as well as their interaction with one another. The selected variables that were analysed to look at the effects mentioned above were accuracy, RT, and WD.

The aim of this research was to determine the interaction between linguistic and speech motor processes in PWA. As aphasia is a heterogeneous disorder, it was vital for us to implement an individual level analysis which assists in creating a precise measurement of the influence of the linguistic and semantic processes on each patient in the picture-naming task. Data was analysed on the basis of participants' responses to the following research aims:

Research aim 1 - To investigate the influence of manipulations of linguistic and speech motor processes on the performance of PWA and HC on a picture-naming task, on the following variables: Accuracy, Reaction time, and Word duration.

We expect that in all three variables (accuracy, RT, and WD), HC will perform better than PWA. We also expect that both groups will exhibit a decrease in accuracy, increase in RT's, and increase in WD's in the homogenous conditions when compared to the heterogeneous conditions, and in articulatory complex words when compared to articulatory simple words. The PWA will be more affected by these manipulations as exhibited by lower accuracy scores, longer RT's and WD's in homogenous conditions and on words that are considered complex. We also expect to have an interaction between blocking and complexity, where words that are considered complex and in homogenous conditions will incur more errors, longer RT's, and longer WD's, compared to the same words in the heterogeneous conditions.

Research aim 2 - Does the fluency of speech in PWA (fluent vs non-fluent) affect the influence of linguistic and speech motor processes during picture-naming?

The interaction between linguistic and speech motor processes is expected to be exacerbated in the participants with non-fluent aphasia, as research in the previously discussed sections indicated that non-fluent people with aphasia exhibit a greater increase in speech motor deficits than people with fluent aphasia.

Research aim 3 - Does the influence of linguistic and speech motor processes depend on the individual participant characteristics in PWA?

We hypothesise that all PWA, regardless of type and severity, will display some kind of deficit in linguistic and speech motor processes, with the influence of these being affected to a higher degree as the severity of aphasia increases and as fluency decreases.

3.4 Methods

3.4.1 Participants

Seventeen PWA and seventeen HC were recruited for this study. The selection criteria for the PWA was: (a) single left hemisphere cardiovascular accident as determined by neuro-radiological and neurological examinations; (b) a diagnosis of aphasia on a standardised clinical test (Western Aphasia Battery- Revised, Kertesz, 2006); (c) at least six months post-stroke; (d) no co-existing history of other neurological illness, psychiatric disorders or substance abuse; (e) no other significant cognitive deficits that might interfere with the individuals performance in the study (based on the Oxford Cognitive Screen); (f) monolingual English speaking; and (g) primarily right-handed.

At the time of testing, the PWA ranged from 3 to 15 years post-onset of stroke (*M*=8. 29, SD= 3.75). The PWA group (12 males, and 5 females) ranged from 36 to 79 years of age (*M*=63.29, SD= 11.06), and education level from 13 to 21 years (*M*= 14.94, SD= 2.44). The HC group ranged from 37 to 81 years of age (*M*= 67.47, SD= 9.94, 8 males, 9 females) and an education level between 13 and 16 years (*M*= 14.65, SD= 1.41). The PWA and the HC participants were matched for age and years of education [age (t= 1.20, *p* <.24), years of education (t = -.45, *p* <.66)]. Individual detailed demographic information for the PWA and the HC can be seen in the Table 3.1 below.

Table 3.1: *Demographic Information for PWA and HC*

PWA					**HC**			
Participant	Age	Gender	Years of education	YPO	Participant	Age	Gender	Years of education
DT	67	M	21	3	HC 25	73	M	14
CB	65	M	14	14	HC 2	70	F	15
WM	66	M	13	4	HC 17	75	F	13
RB	45	M	16	6	HC 12	75	M	16
IB	64	M	13	9	HC 13	69	M	16
CD	72	M	16	10	HC 23	81	M	16
CM	65	F	16	6	HC 1	70	F	14
RR	36	M	16	8	HC 20	75	M	16
SA	51	F	16	4	HC 19	68	M	13
PW	68	F	13	11	HC 10	67	F	13
CB (2)	78	M	13	12	HC 27	64	F	13
PS	55	M	13	15	HC 18	62	F	16
HF	64	F	14	6	HC 16	74	M	16
EM	70	F	13	12	HC 5	59	F	13
CW	68	M	13	3	HC 14	37	F	16
BH	79	M	15	9	HC 15	58	M	13
NH	63	M	19	9	HC 3	70	F	16
MEAN	63.29		14.94	8.29	Mean	67.47		14.65
SD	11.06		2.33	3.75	SD	9.94		1.41

Notes. YPO: Years post-stroke onset

Recruitment for the PWA and the HC adults was accomplished through the use of research panels provided by the School of Clinical Language Sciences, University of Reading (PWA: Aphasia Research Registry and HC: Adult Research Panel). The participants in the study were all independent community-dwelling adults. Prior to testing, both groups of participants gave informed consent in accordance with the University of Reading ethics committee (ethics # 2018-062-AB).

Prior to participation in the experiment, the HC participants completed a questionnaire on their health and reported no history of language, neurological and/or psychiatric deficits or substance abuse, and no uncorrected hearing or visual impairments. The HC participants were also administered speech and cognitive screening tests to guarantee the absence of any word production deficits. The diadochokinetic rate (DDK) was used as a verbal speech measure (Fletcher, 1972), where a reduced rate on the DDK can be indicative of ageing changes or speech impairments such ataxia, apraxia of speech, and dysarthria. All the HC performed within the normal limits for speech rates and no speech motor deficits were apparent. Similarly, their cognitive status was tested using the Mini-Mental State Examination (MMSE) (Folstein M.F., Folstein S.E., McHugh P.R., 1975), a 30-point questionnaire where all the participants performed above the cut-off limit (i.e. >24, adjusted for education).

3.4.1.1 Type and severity of aphasia. The type and severity of aphasia for the PWA was determined by the WAB-R. The WAB-R taps into and assesses four main language areas: spoken language, auditory comprehension, repetition, and naming. The performance of the PWA on the WAB-R yields a total score, also known as the Aphasia Quotient (AQ), which is then used to determine the type and severity of aphasia. The Aphasia Quotient mean for the PWA was 78.59 while the SD was 13.44. A score between 0-25 is considered very severe, 26-50 severe, 51-75 moderate, and 76- above mild. Based on the results of the WAB-R, it was concluded that all the PWA had mild to moderate aphasia. Participants were diagnosed with a subtype of either fluent aphasia (Anomia, Conduction, Wernicke, Transcortical sensory) or a subtype of non-fluent aphasia (Broca, Transcortical Motor, Global, and Isolation). In frequency of order, aphasia types were: Broca's (6 participants), Anomic (6), Conduction (3), and Transcortical Motor (2). The scores for the PWA on the WAB-R are presented in Table 3.2. Due to fluency being particularly subjective and difficult to classify, intra and inter-rater reliability was subjected to the first section of the WAB (fluency and information content) to increase the reliability of the aphasia diagnosis.

Two participants with aphasia, NH and HF, scored above the WAB-R AQ cut-off score of a 93.8 for a diagnosis of aphasia. NH had an AQ score of a 94.2 and HF was 94.2=4. Despite scoring within the normal range, those participants reported that aphasia impacted their language and everyday lives. The influence of aphasia on those two participants was also noticeable in the tasks conducted in this study in that they exhibited obvious difficulties in word-finding and discourse. Therefore, given the difficulty in recruiting PWA and the impact of aphasia on the two participants, we decided to include the above participants in this study. It is worth noting that there have been countless studies that have included participants who scored above the WAB's cut-off in the aphasia group of their studies (Cruice, Pritchard, Dipper, 2014; Fromm et al., 2017; Papanicolaou, Moore, Deutch, Levin, & Eisenberg, 1988; Ross & Wertz, 2003; Sekine & Rose, 2013; Ulatowska et al., 2001; Ulatowska, Reyes, Santos, & Worle, 2011; Wilson et al., 2012).

Table 3.2: *Scores for the People with Aphasia Group on the Western Aphasia Battery – Revised*

	DT	CB	WM	RB	IB	CD	CM	RR	SA	PW	CB 2	PS	HF	EM	CW	BH	NH	Mean	SD
Spontaneous Speech (SS)																			
Information Content	9	8	9	8	9	6	9	9	9	9	5	9	9	7	8	9	9	8.29	1.24
Fluency	9	4	6	4	5	4	9	4	6	5	4	9	9	4	6	8	9	6.18	2.10
SS Score	18	12	15	12	14	10	18	13	15	14	9	18	18	11	14	17	18	14.47	2.98
Auditory Verbal Comprehension (AVC)																			
Yes/No questions	60	54	60	48	60	57	60	60	60	60	57	60	60	60	57	60	60	58.41	3.26
Auditory word recognition	58	55	58	57	60	57	60	58	58	60	57	59	60	57	55	56	60	57.94	1.51
Sequential commands	80	17	60	22	80	70	80	52	67	76	72	64	80	59	67	74	72	64.24	19.20
AVC Score	9.9	6.3	8.9	6.3	10	9.2	10	8.5	9.2	9.8	9.3	9.1	10	8.8	8.95	9.5	9.6	9.02	1.15
Repetition																			
Repetition	91	46	66	50	80	44	96	49	92	51	38	66	94	78	56	90	98	69.71	20.37
Repetition Score	9.1	4.6	6.6	5	8	4.4	906	4.6	9.2	5.1	3.8	6.6	9.4	7.8	5.6	9	9.8	59.68	224.34
Naming																			
Object naming	58	40	54	57	60	40	60	58	60	54	49	50	60	59	42	60	60	54.18	6.70
Fluency	7	4	10	4	14	6	12	11	16	13	6	8	8	6	5	12	17	9.35	3.61
Sentence completion	7	8	10	10	10	8	10	8	10	7	7	10	10	10	9	10	10	9.06	1.26
Responsive speech	9	3	10	8	10	8	10	10	10	10	10	9	10	10	8	10	10	9.12	1.78
Naming Score	8.1	5.5	8.4	7.9	9.4	6.2	9.2	8.7	9.6	8.4	7.2	7.7	9.8	8.5	6.4	9.2	9.7	8.23	1.18
Aphasia quotient (AQ)	90.2	56.8	77.8	62.4	92.8	59.6	93.6	69.6	86	74.6	58.6	83.6	94.4	72.2	72.9	89.4	94.2	78.16	13.23
Aphasia severity	Mild	Moderate	Moderate	Moderate	Mild	Moderate	Mild	Moderate	Mild	Moderate	Moderate	Mild	Mild	Mild	Moderate	Mild	Mild		
Aphasia type	Anomia	Broca	Conduction	Broca	TCM	Broca	Anomia	Broca	Broca	Broca	Broca	Conduction	Anomia	TCM		Anomia			

3.4.1.2 Oxford Cognitive Screen (OCS). The OCS was used to assess the PWA's cognitive profiles. The OCS consists of ten tasks that tap into five cognitive domains: attention and executive function (broken hearts and trails tasks), language (picture naming and semantics tasks), memory (orientation, verbal, and episodic memory tasks), number processing (number writing and calculations tasks), and praxis (imitation tasks). Furthermore, it includes a brief evaluation of visual field defects. Final scoring provides a diagnosis of either spared or impaired in regard to the five cognitive domains. Any score below the norm is considered an impairment as shown in the Table 3.3 below.

Table 3.3: *Oxford Cognitive Screen Scoring and Norm Scores*

	Task Order	Task Name	Maximum Score	Norm
Language Domain	1	Picture naming	4	3
	2	Semantics	3	3
	3	Sentence Reading	15	14
Memory Domain	4	Recall and Recognition	4	3
	5	Orientation	4	4
Number Domain	6	Number Writing Calculation	3 4	3 3
Attention Domain	7	Broken Hearts	50	42
	8	Trails	13	4
Praxis Domain	9	Imitation	14	8
Hemianopia	10	Visual Field	4	4

As a group, the PWA were spared in the areas of attention, praxis, and number but were diverse in the language domain as well as the incidence of hemianopia. The scoring for the PWA in the five domains and hemianopia can be seen in Table 3.4.

Table 3.4: *Domains for the Oxford Cognitive Screen and the Scores for the People with Aphasia*

Participant	**Domains**					**Hemianopia**
	Attention	***Memory***	***Praxis***	***Number***	***Language***	
DT	✓	✓	✓	✓	x	No
CB	✓	✓	✓	✓	x	No
WM	✓	✓	✓	✓	x	No
RB	✓	✓	✓	✓	x	No
IB	✓	✓	✓	✓	✓	No
CD	✓	✓	✓	✓	x	No
CM	✓	✓	✓	✓	✓	No
RR	✓	✓	✓	✓	✓	No
SA	✓	✓	✓	✓	✓	No
PW	✓	✓	✓	✓	x	No
CB (2)	✓	✓	✓	✓	x	No
PS	✓	✓	✓	✓	✓	Yes
HF	✓	✓	✓	✓	✓	No
EM	✓	✓	✓	✓	✓	No
CW	✓	✓	✓	✓	x	Yes
BH	✓	✓	✓	✓	x	No
NH	✓	✓	✓	✓	✓	Yes

Key: ✓: spared; X: impaired

3.4.1.3 Background testing to profile speech and language measures for the PWA. A comprehensive evaluation of each individual with aphasia was performed using an extensive battery of tests to determine their pattern of speech, language, and oro-motor deficits. The batteries are divided into the following sections: tests to tap into (a) phonology, including PALPA 8, PALPA 9, PALPA 2; (b) semantics, including PALPA 47, Pyramids and Palm Trees (Howard & Patterson, 1992), Camel and Cactus (Bozeat, Lambon, Ralph, Patterson, Garrad, & Hodges, 2000); (c) the Philadelphia Naming Test (Roach et al., 1996); and (d) speech motor assessments, including oral motor and peripheral examinations, cranial nerve examinations, Apraxia Battery for Adults-2. A brief summary of the experimental tasks used to profile and characterise the PWA group is provided in the Table 3.5 below.

Table 3.5: *Experimental Tasks Used for Profiling and Characterising Aphasia*

Experimental tasks	**Example stimuli used with examples**	**Response type**	**Total no. of items**	**Level of Processing**
		Phonology		
Nonword repetition (PALPA 8)	1- ailty 2- vater 3- splantt 4- crealth	Repetition	Total= 30	Output phonology
Imageability x Frequency repetition (PALPA 9)	1- Church- high imageability/high frequency 2- Potatoes - high imageability/low frequency 3- Idea- low imageability/high frequency 4- Miracle- low imageability/ low frequency	Repetition	Total=80	Output phonology
Same- different discrimination using minimal pairs (PALPA 2)	1- pole/bowl 2- rope/rope 3- tail/sail 4- might/night	Yes/No verbal response	Total =72	Input phonology
		Semantics		
Spoken word-picture matching (PALPA 47)	1- axe →hammer/scissors/ flag/kite 2- television→ radio/ toaster/frying pan/record-player 3- ladder→ steps/rope/ruler/ satchel 4- button→ zip/bow/coin/ bank note	Pointing	Total = 40	Semantic comprehension
Camel and Cactus	1- cat→ mouse/mole/rabbit/weasel	Pointing	Total= 64	

Pyramids and Palm Trees (3 picture version)	2- pear→ roots/tree/flower/grass 3- rhino→ lion/cat/dog/fox 4- axe→ grass/tree/flower/roots 1- mouse→ cage/Kennel 2- razor→ chin/nose 3- fish→ cat/dog curtain→ door/window		Total= 52	Semantic comprehension
		Naming		
Philadelphia Naming Test	1- candle 2- ghost 3- strawberries 4- well	Naming	Total= 175	Lexical access and spoken word production
		Oro-motor assessments		
Apraxia Battery for Adults -2 Oral and peripheral examination	1- DDK rate → /Pa/ /Ta/ /Ka/ 2- Increasing word length → zip/ zipper/zippering 3- Oral apraxia → stick out your tongue 1- Rate of speech 2- Drooling 3- Swallowing 4- Movement of tongue, lips, and jaw	Repetition, gestures, naming Motions and gestures	Numerous items within each task	Oral motor control

3.4.1.3.1 Assessing input and output phonology. To assess auditory discrimination and the participant's judgment of real-word minimal pairs the PALPA #2 was used. In this task the participants are asked to listen to 72 monosyllabic stimulus pairs (e.g., might-night) that vary in voice, manner, or place of articulation, and then make a judgment as to whether the pairs they heard are the same or different. This task is able to help in the identification of phoneme perception impairment. As a group, the scores for the PWA ranged from 76% to 100%, (*M*= 66.31, SD= 6.15).

Non-word and word repetition tasks (PALPA #8 and #9) were used to assess the integrity of repetition skills, as it was one of the elicitation modes in the experiments. In PALPA #8, participants were asked to repeat 30 words that were non-words but included word-like sound forms (e.g., egular, gaffic, and truggle). The length of the repeated words varied between one and three syllables. Any difficulties that arise when increasing syllable length may indicate an issue of concern at the level of the phonological output buffer or below (Kay, Lesser, & Coltheart, 1992). The scores for this test varied among the PWA, where the lowest score was 0% due to the participant being unable to correctly repeat any of the targeted words, while the highest score was 100% (M= 21.29, SD= 7.43).

In PALPA #9, repetition was assessed using real words while manipulating their imageability and frequency. This task required participants to name 80 words that were divided equally among the following categories: High Imageability/High Frequency (e.g., church), High Imageability/Low Frequency (e.g., potatoes), Low Imageability/High Frequency (e.g., idea) and Low Imageability/Low Frequency (e.g., clue). Errors with imageability indicate that the participant is relying on the semantic system for naming. The PWA performed well in this task with percentages that ranged from 83% and 100% except for one participant who got 61%. Many of the errors were on Low Imageability/High Frequency (29 errors, *M*= 2.07, SD= 3.1) and Low Imageability/Low Frequency (29 errors, *M*= 2.07, SD= 3.17).

3.4.1.3.2 Assessing conceptual and lexico-semantic processing. As semantic processing is the emphasis of this research, it was important to be mindful that semantic naming errors committed in the main picture-naming task were caused by impaired semantic-to-lexical mapping rather than dysregulated semantics or degraded semantic/lexical representations. Therefore, several tasks were used to assess semantic processing.

The picture version of the Pyramids and Palm Trees test (Howard & Patterson, 1992) was administered to the PWA. The Pyramids and Palm Trees test is a nonverbal test of conceptual semantics where participants are shown 52 items with three pictures and are required to judge which of the bottom two pictures (e.g. chin and nose) is associated with the top picture (razor). The participants are asked to only point to the targeted answer and refrain from naming the pictures. The scores for the PWA ranged between 81% to 100% (*M*= 48.88, SD= 3.34).

The Camel and Cactus test, similar to the Pyramids and Palm Trees test, was also used to assess semantic processing. This test has 64 test items, where participants are shown a one-target picture and four semantically related items and then asked to decide which out of the four semantically related items is most associated with the targeted stimulus (e.g., does piano go with deck chair, stool, arm chair, or rocking chair). The PWA scored between 73% to 98% (M= 56.5, SD= 5.19).

The spoken word-to-picture matching (PALPA #47) was also used to evaluate semantic processing. This task has 40 picture stimuli which are used to assess semantic comprehension ability and require the participant to match a spoken word (e.g., carrot) with one of the five pictures (i.e., carrot, cabbage, lemon, saw, and chisel). The five pictures include the targeted item and four distractors. The four distractors consist of two semantically related items (cabbage, close semantic distractor and lemon, distant semantic distractor), one visually related item (saw) and an unrelated item (chisel). The PWA scored between 85% and 100% (M= 39.35, SD= 1.58).

To conclude, as a group, the PWA showed variable impairments both for input and output phonology but with better preserved conceptual and lexical semantics (as tested by the PPT, CCT, and PALPA # 47). Participants RB and CB (2) were the only two PWA that exhibited impairments in conceptual and lexical semantics. Table 3.6 provides a summary of the scores from the test batteries discussed above.

Table 3.6: *Summary of the Scores for the Tests Assessing Conceptual and Lexico- Semantic Processing for the People with Aphasia*

	DT	CB	WM	RB	IB	CD	CM	RR	SA	PW	CB (2)	PS	HF	EM	CW	BH	NH	Mean	SD
									Phonology										
PALPA 2 (n=72)	71	69	72	55	70	58	71	70	72	67	55	70	70	63	59	69	72	66.31	6.15
Percentage	99%	96%	100%	76%	97%	81%	99%	97%	100%	93%	76 %	97%	97%	88%	82%	96%	100%	92%	.086
Errors																			
Same	1	2	0	0	0	0	1	0	0	5	15	0	0	7	0	3	0	2.13	4.01
Different	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Low Freq	0	1	0	0	0	0	0	0	0	2	9	0	0	2	0	2	0	1	2.28
High Freq	0	1	0	0	0	0	1	0	0	3	7	0	0	5	0	1	0	1.13	2.09
PALPA #8: Nonword repetition (n=30)	23	28	all error	CNT	30	20	30	22	26	21	11	20	22	3	16	26	30	21.29	7.43
Percentage	77%	93%	0%	CNT	100%	67%	100%	73%	87%	70%	37 %	67%	73%	10%	53%	87%	100%	68%	.030
Errors				CNT															
1 syllable	4	0	10	CNT	0	4	0	1	1	5	8	5	4	9	7	3	0	4.07	3.33
2 syllables	2	1	10	CNT	0	1	0	2	2	2	0	3	2	10	4	1	0	2.67	3.18
3 syllables	1	1	10	CNT	0	5	0	4	1	3	0	2	2	8	3	0	0	2.67	3.02
PALPA #9: Imageability × frequency word repetition (n=80)	80	80	80	CNT	80	76	80	65	80	76	49	69	74	66	CNT	80	80	73.93	9.01
Percentage	100%	100%	100%	CNT	100%	95%	100%	81%	100%	95%	61 %	86%	93%	83%	CNT	100%	100%	92&	.110
Errors				CNT											CNT				
HI HF	0	0	0	CNT	0	0	0	1	0	0	3	0	0	3	CNT	0	0	0.5	1.09
HI LF	0	0	0	CNT	0	0	0	4	0	2	7	3	1	3	CNT	0	0	1.43	2.14
LI HF	0	0	0	CNT	0	3	0	4	0	1	11	2	3	5	CNT	0	0	2.07	3.1
LI LF	0	0	0	CNT	0	1	0	6	0	1	10	6	2	3	CNT	0	0	2.07	3.12

Semantics

Pyramid and Palm Tree Test- 3-Picture version (n=52)	50	49	52	42	52	51	51	51	50	52	43	49	52	48	45	45	51	48.88	3.34
Percentage	96%	94%	100%	81%	100%	98%	98%	98%	96%	100%	83%	94%	100%	92%	87%	87%	98%	94%	.061
	DT	CB	WM	RB	IB	CD	CM	RR	SA	PW	CB (2)	PS	HF	EM	CW	BH	NH	Mean	SD
Camel and Cactus Test (CCT) (n=64)	59	54	61	49	59	54	57	63	61	63	47	54	61	59	48	55	56	48.88	3.34
Percentage	92%	84%	95%	77%	92%	84%	89%	98%	95%	98%	73%	84%	95%	92%	75%	86%	88%	88%	.077
PALPA #47: Spoken word-Picture matching (n=40)	40	40	40	34	40	40	40	40	40	40	37	39	40	40	40	39	40	39.35	1.57
Percentage	100%	100%	100%	85%	100%	100%	100%	100%	100%	100%	93%	98%	100%	100%	100%	98%	100%	98%	.030

3.4.1.3.3 Assessing picture-naming. Picture-naming is a main task in this research; therefore a precise characterisation of picture-naming in the PWA group was desired prior to the experimental manipulation. The PNT was selected as a means of assessment due to the large number of items that must be named, in turn providing a clear understanding of the nature and severity of impairments in picture-naming in the PWA. The standard PNT administration procedure was followed, where the 175 picture stimuli were displayed on a computer screen one at a time. The participants were asked to name each picture as soon as it appeared on the screen. However, there was no time limit given to respond. The names of the pictures in the PNT varied in the number of syllables (between one and four syllables) and included a varied frequency range.

Naming responses were recorded and used to analyse accuracy and error patterns. The standard administration for the analysis of the responses declares the first complete identified response as the response that is to be analysed. This proved to be challenging as many of the participants produced initial incomplete attempts in naming some pictures. Therefore, using the criteria by Roach et al. (1996), any use of single phonemes, constants or fillers (e.g., um, uh) were ignored. Responses were scored as correct if the correct name of the picture was produced. All incorrect responses were scored as errors and followed the criteria in Table 3.7.

Table 3.7: *Descriptions of Error Types in the PNT with Examples*

Error type	Criteria	Examples
Non-word	Items that would not be considered a real English word (checked where necessary in a standard British English dictionary).	*dog – nog* *apple – strumf*
Semantic	Items related in meaning to the target. This includes category subordinate or superordinate terms, associations, and synonyms.	*shoe – clog (subordinate)* *fork – cutlery (superordinate)* *saddle – horse(association)* *light – lamp (synonym)*
Formal	Responses that are phonologically related to the target. Following the PNT, this includes items that begin or end with the same phoneme as the target or have a phoneme in common at another corresponding syllable, word position, or contain two or more target phonemes in any position.	*dog – desk (initial phoneme)* *pin – can (final phoneme)* *chain –tape (corresponding word position)* *table – belt (two phonemes, any position)*
Mixed	Mixed errors are related both in form and meaning to the target.	*tractor – train (semantic association; shared onset)* *cat – rat (semantic association; shared coda)*
Miscellaneous	This category includes picture part responses, blends, and phoneme omission.	*suit – trousers (picture-part)* *pineapple-banaeple (blend of pineapple and banana)* *ruler- rule*
No Response	Participant does not produce an answer at all or indicates that they are not able to, as well as sound effects.	
Description	This includes descriptions of the picture stimuli.	*Cheerleaders - girls dancing*

The PNT was the only background test where both groups of participants (PWA and HC) were assessed. As a group, the PWA varied greatly in their picture-naming abilities (PNT scores ranged from 54 to 170, *M*= 140.64, SD= 38.38). In frequency of order, error types for the PWA were as follows: (a) no responses to naming the picture (total number of errors 271, *M*= 19.29, SD= 28.43), (b) semantic (total number of errors 112, *M*= 7.64, SD= 6.54), (c) description (total number of errors 79, *M*= 5.29, SD= 6.03), (d) miscellaneous (total number of errors 17, *M*=

1.14, SD= 1.70), (e) formal (total number of errors 15, *M*= 0.36, SD= 0.84), (f) non-word (total number of errors 4, *M*= 0.29, SD= 0.73), and (f) mixed (total number of errors 2, *M*= 0.14, SD= 0.36). In regards to the HC, the same scoring scheme was used. The total scores for both the PWA and the HC can be seen in Table 3.8 below.

Table 3.8: *Philadelphia Naming Test Scores for the People with Aphasia and Healthy Controls*

People with Aphasia	DT	CB	WM	RB	IB	CD	CM	RR	SA	PW	CB (2)	PS	HF	EM	CW	BH	NH	Mean	SD
Philadelphia Naming Test (N= 175)	149	154	169	CNT	152	CNT	174	134	168	150	70	100	170	161	54	164	163	39.35	1.58
Percentage	85%	88%	97%		87%		99%	77%	96%	86%	40 %	57%	97%	92%	31%	94%	93%	81%	.21
<u>Errors</u>																			
Formal	1	0	2		0		0	8	0	0	3	0	0	0	0	1	0	0.36	0.84
Semantic	10	12	0		3		0	13	4	6	23	15	4	1	8	8	5	7.64	6.54
Mixed	0	1	0		0		0	0	0	0	0	0	0	0	0	1	0	0.14	0.36
Description	6	2	0		1		0	17	1	8	14	10	0	2	13	0	5	5.29	6.03
Neologism	2	0	2		0		0	0	0	0	0	0	0	0	0	0	0	0.29	0.73
Misc	0	1	0		0		0	1	1	2	3	2	0	0	6	0	1	1.14	1.7
No response	7	7	2		19		1	0	0	9	62	48	1	11	94	8	1	19.29	28.43

Note: CNT- could not test.

Healthy Controls	HC1	HC2	HC3	HC5	HC 10	HC 12	HC 13	HC 14	HC 15	HC 16	HC 17	HC 18	HC 19	HC 20	HC 23	HC 25	HC 27	Mean	SD
Philadelphia Naming Test (N= 175)	161	174	169	175	166	171	165	163	164	162	172	171	168	173	170	174	171	168.76	4.49
Percentage	92%	99%	97%	100 %	95%	98%	94%	93%	94%	93%	98%	98%	96%	99%	97%	99%	98%	96%	.025
<u>Errors</u>																			
Formal	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0.18	0.53
Semantic	11	0	2	0	6	0	5	10	5	4	2	4	3	0	4	1	4	3.59	3.26
Mixed	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0.12	0.33
Description	2	1	2	0	2	0	3	1	1	4	0	0	2	0	1	1	0	1.18	1.19
Neologism	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00
Misc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00
No response	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00

3.4.1.3.4 Oral motor assessments. An oral and peripheral examination and a cranial nerve examination was conducted to assess the adequacy of the structures and functions required for speech production. The Apraxia Battery for Adults (Dabul, 2000) was also used to identify apraxia of speech in the PWA.

Based on the literature, the four features of apraxia of speech are: increased impairments of speech with the increase of word length and during repeated trials, increase in utterance time for polysyllabic words, and oral apraxia (McNeil & Kent, 1990). Based on the above features and the combination of the oral and peripheral examinations, a diagnosis of apraxia was made. Table 3.9 below provides a brief summary for the scores of the PWA on the subtests of the Apraxia Battery.

Table 3.9: *Overall Summary of the Scores for the PWA on the Apraxia Battery for Adults*

Cut-off scores for determining level of impairments

	None (N)	Mild (Mi)	Moderate (Mo)	Severe (S)
Diadochokinetic rate	26+	7-25	2-6	0-1
Increasing word length (1)	0-1	2-4	5-7	8+
Increasing word length (2)	0-1	2	2-5	6+
Limb Apraxia	44-50	37-43	25-36	0-24
Oral Apraxia	44-50	37-43	21-34	0-20
Utterance time for polysyllabic words	0-15	16-55	56-80	81-100
Repeated trials	28-30	16-27	5-15	0-4

	DT	CB	WM	RB	IB	CD	CM	RR	SA	PW	CB (2)	PS	HF	EM	CW	BH	NH
Diadochokinetic rate	27	25	24	6	18	5	28	28	25	25	6	5	27	5	27	27	29
Impairment	N	Mi	Mi	Mo	Mi	Mo	N	N	Mi	Mi	Mo	Mo	N	Mo	N	N	N
Increasing word length (1)	0	1	3	5	0	2	0	2	0	4	2	6	0	1	1	0	0
Impairment	N	N	Mi	Mo	N	Mi	N	Mi	N	Mi	Mi	S	N	N	N	N	N
Increasing word length (2)	1	6	7	6	2	10	0	13	3	18	9	4	0	4	0	2	0
Impairment	N	S	S	S	Mi	S	N	S	Mo	S	S	Mo	N	Mo	N	Mi	N
Limb Apraxia	50	50	50	50	50	50	50	50	50	50	45	50	50	50	50	50	50
Impairment	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Oral Apraxia	50	50	50	50	50	50	50	50	50	50	30	50	50	50	50	50	50
Impairment	N	N	N	N	N	N	N	N	N	N	Mi	N	N	N	N	N	N
Utterance time for polysyllabic words	7	55	26	57	37	7	11	45	0	10	87	50	3	21	14	14	6
Impairment	N	Mi	Mi	Mo	Mi	N	N	Mi	N	N	S	Mi	N	Mi	N	N	N
Repeated trials	30	30	11	12	29	3	30	8	26	18	4	27	30	21	30	30	0
Impairment	N	N	Mo	Mo	N	S	N	Mo	Mi	Mi	S	Mi	N	Mi	N	N	S
Number of Apraxia features	0	3	5	5	3	4	0	5	3	4	5	4	0	4	0	1	1
Apraxia Diagnosis	X	✓	✓	✓	X	✓	X	✓	✓	✓	✓	✓	✓	✓	X	X	X
Aphasia severity	Mi	Mo	Mo	Mo	Mi	Mo	Mi	Mo	Mi	Mo	Mo	Mi	Mi	Mi	Mo	Mi	Mi
Aphasia type	Anomia	Broca	Conduction	Broca	TCM	Broca	Anomia	Broca	Broca	Broca	Broca	Conduction	Anomia	TCM	Anomia	Anomia	Anomia

Note: ✓- yes; X-No, Mi- Mild; Mo- moderate

Additionally, the motor speech examinations revealed no significant or abnormal abilities in muscle tone, strength, or function and revealed no dysarthria. A summary of the results can be seen in Table 3.10 below.

Table 3.10: *Summary Scores of PWA on Speech Motor Tests*

	DT	CB	WM	RB	IB	CD	CM	RR	SA	PW	CB(2)	PS	HF	EM	CW	BH	NH
DDK																	
/pa/	16.3	16.6	11.6	NA	9.3	13	8.3	12	9.6	17.6	17	21.3	9	12.3	11	17.6	22
/ta/	19.3	16	13.3	NA	10.6	13.6	11.6	15.6	12.0	16.6	6	21.3	10.6	11.6	14.5	18.3	21
/ka/	24	14	10.3	NA	10	13.4	10.6	10.6	11.3	10	9	16	11.3	15	9.6	16.6	15
/pataka/	11	9.6	4.3	NA	9.3	12	5.6	4.6	5	6	2	7	7.3	0	6.6	5.6	7
Oro-motor control																	
Rate of speech	✓	✓	X	✓	✓	X	✓	✓	X	✓	X	✓	✓	X	✓	✓	✓
Swallowing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Drooling	✓	✓	X	✓	✓	X	✓	✓	X	✓	X	✓	✓	X	✓	✓	✓
Cranial nerve exam	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Praxis	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Apraxia Features																	
Increasing word length	✓	✓	X	X	X	X	✓	X	X	X	X	X	✓	X	✓	X	✓
Repeated trials	✓	X	X	X	X	X	✓	X	X	X	X	X	✓	X	✓	✓	X
Polysyllabic words	✓	✓	X	X	X	X	✓	X	X	X	X	X	✓	X	✓	✓	✓
Oral apraxia	✓	✓	X	X	✓	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓

Key: DDK: diadochokinetic, DDK rate= per 5 seconds, ✓: Within normal limits; X: impaired/slow, NA- not available

As shown in Tables 3.9 and 3.10 above, five PWA (BH, CM, CW, DT, HF) did not exhibit speech motor impairments at all, as no deficits were found in any of the various speech motor assessments. Furthermore, three PWA (CB, IB, NH) displayed mild speech motor impairments while six PWA (CD, EM, PS, PW, RR, SA) exhibited mild to moderate speech impairments, manifested by a slightly slowed speech rate, reduced ability to repeat words, reduced ability to produce words with an increased syllable length, and reduced ability to produce the diadochokinetic rate. Finally, three PWA (CB- 2, RB, and WM) displayed a moderate to severe speech motor impairment, with their speech exhibiting a reduced overall speech rate, phoneme distortions, distorted substitutions, additions, and voicing errors. To conclude, the speech motor involvement in the 12 PWA participants did not affect their speech to the extent that it would not qualify them to participate in the study.

To conclude, Table 3.11 below provides a summary of the scores from the various language, speech, and motor background batteries used to assess all the participants with aphasia. The Crawford and colleagues' statistical analysis method (Crawford et al. 2010) was implemented in the assessment of each participant score on each battery to determine the presence of an impairment when compared to normative data. Shading on the table indicates where participants were impaired relative to controls.

Table 3.11: *Summary Scores and Results for the Background Test for the People with Aphasia*

	Aphasia Type	AQ	Output phonology		Input phonology	Semantic comprehension			Lexical access and spoken word production	Motor speech
			PALPA 9	PALPA 8	(PALPA 2)	PALPA 47	CC	PPT	(PNT)	(Apraxia Battery for Adults)
DT	Anomia	90.2	100%	77%	99%	100%	92%	96%	85%	X
CB	Broca	56.8	100%	93%	96%	100%	84%	94%	88%	✓
WM	Conduction	77.8	100%	0%	100%	100%	95%	100%	97%	✓
RB	Broca	62.4	CNT	CNT	76%	85%	77%	81%	CNT	✓
IB	TCM	92.8	100%	100%	97%	100%	92%	100%	87%	X
CD	Broca	59.6	95%	67%	81%	100%	84%	98%	CNT	✓
CM	Anomia	93.6	100%	100%	99%	100%	89%	98%	99%	X
RR	Broca	69.6	81%	73%	97%	100%	98%	98%	77%	✓
SA	Anomia	86	100%	87%	100%	100%	95%	96%	96%	✓
PW	Broca	74.6	95%	70%	93%	100%	98%	100%	86%	✓
CB 2	Broca	58.6	61%	37%	76%	93%	73%	83%	40%	✓
PS	Conduction	83.6	86%	67%	97%	98%	84%	94%	57%	✓
HF	Anomia	94.4	93%	73%	97%	100%	95%	100%	97%	✓
EM	TCM	72.2	83%	10%	88%	100%	92%	92%	92%	✓
CW	Conduction	72.9	CNT	53%	82%	100%	75%	87%	31%	X
BH	Anomia	89.4	100%	87%	96%	98%	86%	87%	94%	X
NH	Anomia	94.2	100%	100%	100%	100%	88%	98%	93%	X

[highlight] = indicates impairment as identified by the Singlims statistical application (Crawford et al., 2000), ✓: apraxia of speech

Note: AQ= Aphasia Quotient, TCM= transcortical motor, CC= camel and cactus, PPT= pyramids and palm trees, PNT= Philadelphia Naming Test, RT= reaction time, WD= word duration, CNT= could not be tested

3.5 Stimuli, Design, & Procedure

The stimuli, design, and the procedures for this chapter are the same as the ones described in Chapter 2.

3.6 Response Analysis, Outlier Analysis, Statistical Design, Factors

3.6.1 Response Analysis

Similar to Chapter 2, responses for every trial were transcribed verbatim. Each trial was then coded for accuracy, RT, and WD.

3.6.1.1 Accuracy and error analysis. The same coding system implemented in Chapter 2 was used. The removal of the inaccurate responses resulted in the exclusion of 9% (n= 316) of items across the HC participants. Across the PWA participants, error removal resulted in the exclusion of 27% (n= 940) of the items in the naming task. Individual level data for the accurate responses of both the PWA and the HC in each condition and for both complexity levels can be seen in Table 3.12 below.

3.6.2 Outlier Analysis

The same two-step outlier procedure that was used in Chapter 2 was used in this chapter, with the removal of outliers per subject per condition. These procedures affected less than .97% of the data for the HC (32 responses were eliminated) and 1.9% of the data for the PWA (64 responses were eliminated).

3.6.3 Statistical Design

Similar to Chapter 2, a repeated measures analysis of variance (ANOVA) was performed for each variable of interest (accuracy, reaction times, and word durations). A two-way between subjects' ANOVA was conducted with alpha levels set at 0.05 for significance. To identify statistically significant results, within group one-way ANOVAs were conducted on the HC and PWA separately.

3.6.4 Factors

Parallel to Chapter 2, the independent variables measured were Blocking Condition (homogenous vs heterogeneous) and Complexity (simple vs complex). Accuracy, reaction times, and word durations were the dependent variables. For the between group ANOVA the factors of interest were Group, Blocking, Complexity, Blocking x Group, Complexity x Group, Blocking x Complexity, and Blocking x Complexity x Group.

Table 3.12: *Accuracy between conditions and complexity for the People with Aphasia and Healthy Controls*

People with Aphasia								Healthy Control							
	Homogenous			Heterogeneous			Overall total (n=200)		Homogenous			Heterogeneous			Overall total (n=200)
	Complex	Simple	Total (n=100)	Complex	Simple	Total (n=100)			Complex	Simple	Total (n=100)	Complex	Simple	Total (n=100)	
DT	27	34	61	26	30	56	117	HC 1	43	47	90	46	45	91	181
CB	32	35	67	33	35	68	135	HC 2	47	46	93	46	46	92	185
WM	38	41	79	35	43	78	157	HC 3	46	47	93	44	46	90	183
RB	28	36	64	29	35	64	128	HC 5	45	45	90	46	46	92	182
IB	35	42	77	31	41	72	149	HC 10	44	46	90	47	48	95	185
CD	32	34	66	32	35	67	133	HC 12	40	41	81	44	45	89	170
CM	48	49	97	47	49	96	193	HC 13	44	45	89	46	46	92	181
RR	33	41	74	41	42	83	157	HC 14	48	49	97	48	49	97	194
SA	44	42	86	44	44	88	174	HC 15	47	47	94	47	47	94	188
PW	38	39	77	40	45	85	162	HC 16	43	48	91	42	50	92	183
CB (2)	23	20	43	18	21	39	82	HC 17	43	42	85	43	44	87	172
PS	14	15	29	23	22	45	74	HC 18	47	49	96	49	47	95	192
HF	49	48	97	49	48	97	194	HC 19	37	39	76	39	41	80	156
EM	44	44	88	44	45	89	177	HC 20	47	48	95	48	48	96	191
CW	23	20	43	16	16	32	75	HC 23	45	43	88	45	42	87	175
BH	46	47	93	48	44	92	185	HC 25	48	46	94	48	47	95	189
NH	42	40	82	42	44	86	168	HC 27	43	46	89	43	44	87	176
Mean	35.06	36.88	71.94	35.59	37.59	72.76	144.71		45.53	45.53	90.06	45.35	45.94	91.24	181.35
SD	9.93	9.98	19.56	10.37	9.98	20.06	39.15		2.94	2.81	5.41	2.60	2.33	4.29	9.45

3.7 Results

The mean and standard deviation values for both groups of participants (HC and PWA) in both naming context (homogenous and heterogeneous) and complexity levels (simple and complex) for all dependent variables (accuracy, reaction time, and word duration) are presented in Table 3.13 below. The results of the ANOVA statistical tests are provided in Table 3.14 below. One-way within group ANOVA's (PWA and HC separately) were conducted to further investigate the interactions found. A two-way within group ANOVA was conducted to explicate the three-way interaction.

Table 3.13: *Descriptive Statistics for People with Aphasia and Healthy Controls on the Blocked Non-cyclical Naming Task*

People with Aphasia				**Healthy Controls**			
Accuracy							
	Simple (n=50)	Complex (n=50)	Total (n=100)		Simple (n=40)	Complex (n=50)	Total (n=100)
Homogenous	36.82 (10.30) 74%	35.00 (9.89) 70%	71.94 (19.56) 72%	**Homogenous**	45.52 (2.81) 91%	44.52 (2.94) 89%	90.23 (4.44) 90%
Heterogeneous	37.65 (9.85) 75%	35.18 (10.37) 70%	72.76 (20.06) 73%	**Heterogeneous**	45.94 (2.33) 92%	45.35 (2.60) 91%	91.29 (5.31) 91%
Overall complexity	74.7 (19.8)	70.1(21.9)		**Overall complexity**	91.6 (4.9)	89.8 (5.3)	
	Overall mean (n=200) 150.58 (49.11) 75%				Overall mean (n=200) 181.35 (9.45) 90.67%		
Reaction Time in ms.							
	Simple	Complex	Total		Simple	Complex	Total
Homogenous	1612.10 (440.22)	1882.68 (649.88)	1742.90 (513.81)	**Homogenous**	769.73 (70.62)	825.76 (99.97)	797.19 (424.13)
Heterogeneous	1313.37 (348.03)	1524.13 (522.76)	1363.19 (423.77)	**Heterogeneous**	731.64 (62.46)	754.53 (66.75)	742.73 (199.52)
Overall complexity	1471.1 (383.5)	1714.9 (574.4)		**Overall complexity**	750.86 (64.5)	790.76 (75.5)	
	Overall mean 1516.12 (865.87)				Overall mean 770.11 (333.11)		
Word Duration in ms.							
	Simple	Complex	Total		Simple	Complex	Total
Homogenous	546.61 (83.01)	709.27 (128.20)	625.78 (208.01)	**Homogenous**	470.16 (58.24)	531.97 (62.64)	501.29 (121.57)
Heterogeneous	506.96 (78.11)	637.64 (113.83)	572.42 (179.22)	**Heterogeneous**	447.25 (54.00)	507.73 (59.73)	476.62 (107.39)
Overall complexity	572.2 (80.1)	673.8 (118.8)		**Overall complexity**	458.8 (55.6)	519.9 (60.4)	
	Overall mean 599.28 (196.03)				Overall mean 489.03 (115.38)		

Note: means are written with standard deviations in parenthesis. Means and standard deviations are after the removal of outliers.

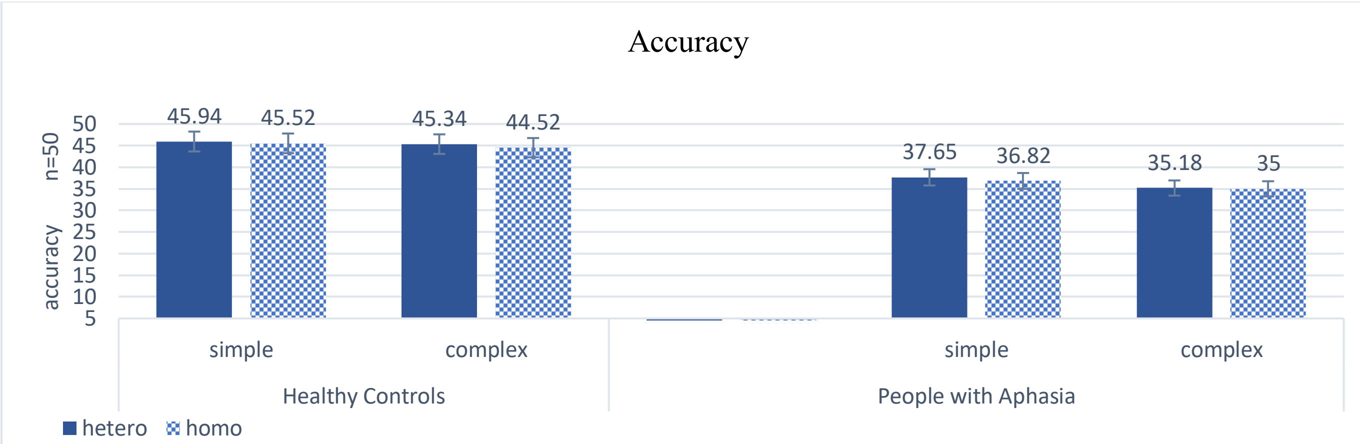


Figure 3.1 Mean accuracy by context (homogenous and heterogeneous) and complexity for each group (healthy controls and people with aphasia). Error bars represent the standard error of the mean.

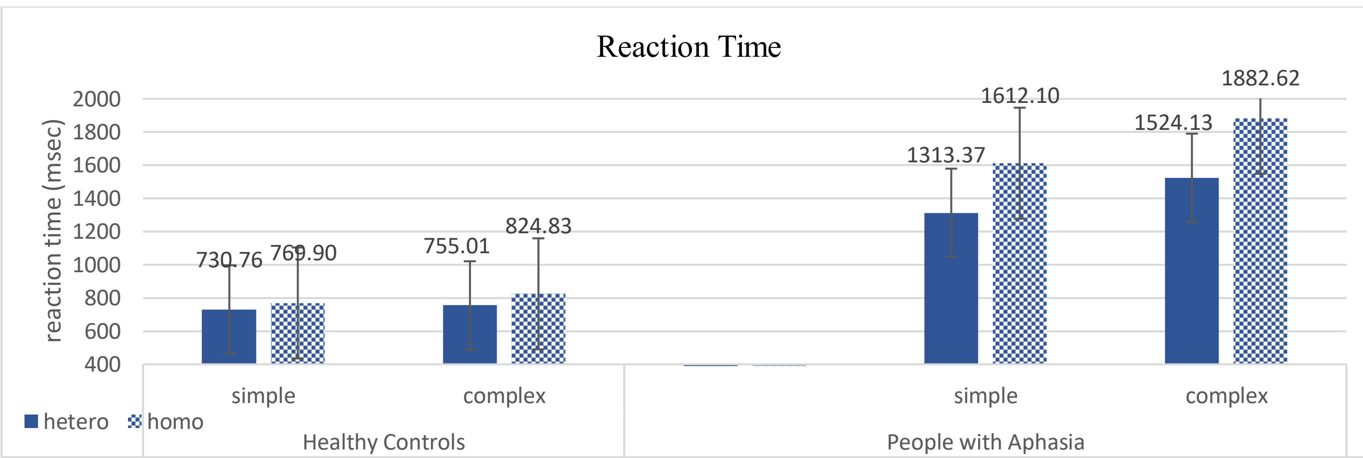


Figure 3.2 Mean RT by context (homogenous and heterogeneous) and complexity for each group (healthy controls and people with aphasia). Error bars represent the standard error of the mean.

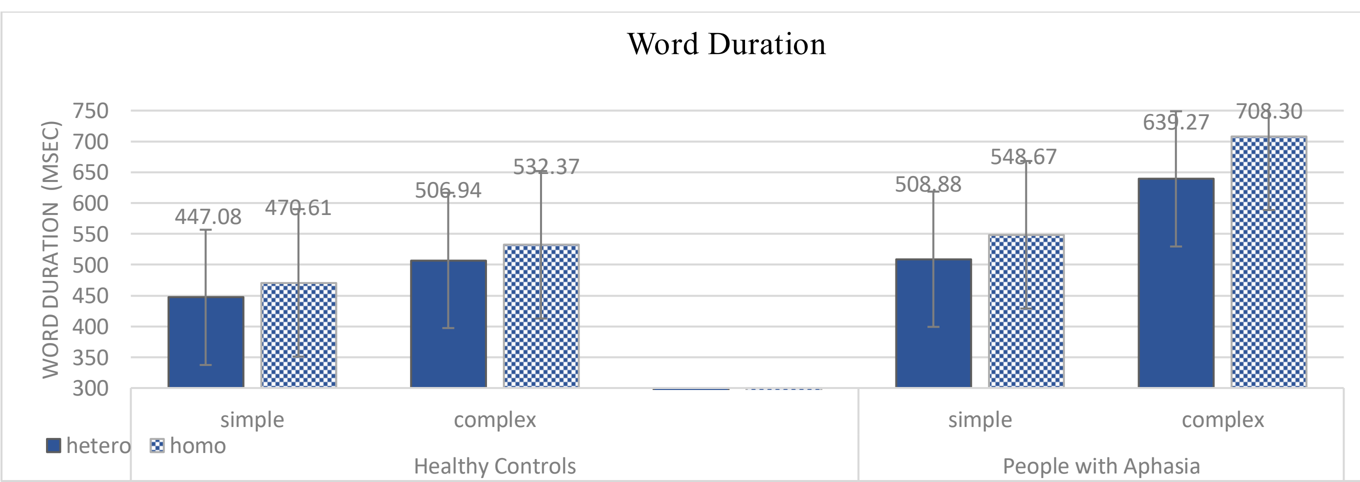


Figure 3.3 Mean WD by context (homogenous and heterogeneous) and complexity for each group (healthy controls and people with aphasia). Error bars represent the standard error of the mean.

Table 3.14: *Results of the Statistical Analysis for the People with Aphasia and Healthy controls.*

	Between Group Analysis	
	Condition	**Statistics Analysis**
Accuracy	Group	F (1, 33) = 14.180, n^{2}= .307, p< .001
	Semantic blocking	F (1,33) = 1.424, $\eta^{2=}$ .041, p=.241
	Articulatory complexity	F (1,33) =11.375, $\eta^{2=}$ .262, p< .002
	Blocking x Complexity	F (1,33) = .013, $\eta^{2=}$ .000, p=.910
	Blocking x Group	F (1,33) = .013, $\eta^{2=}$ .001, p=.900
	Complexity x Group	F (1,33) = 2.036, $\eta^{2=}$ .000, p=.945
	Blocking x Complexity x Group	F (1,330 =1.584, $\eta^{2=}$ .047, p=.217
Reaction Time (ms.)	Group	F(1, 33) = 439.63, n^{2}= .932, p< .000
	Semantic blocking	F (1,33) =39.466, $\eta^{2=}$ .552, p< .000
	Articulatory complexity	F (1,33) =13.241, $\eta^{2=}$ .293, p< .001
	Blocking x Complexity	F (1,33) =2.799, $\eta^{2=}$ .080, p= .104
	Blocking x Group	F (1,33) =20.162, $\eta^{2=}$ .387, p< .000
	Complexity x Group	F (1,33) =6.831, $\eta^{2=}$ .176, p< .014
	Blocking x Complexity x Group	F (1,33) =.230, $\eta^{2=}$ .007, p=.634
Word Duration (ms.)	Group	F (1, 33) = 1606.84, n^{2}= .980, p< .000
	Semantic blocking	F (1,33) =79.071, $\eta^{2=}$ .712, p< .000
	Articulatory complexity	F (1,33) =181.967, $\eta^{2=}$ .850, p< .000
	Blocking x Complexity	F (1,33) =6.592, $\eta^{2=}$ .171, p< .015
	Blocking x Group	F (1,33) =12.768, $\eta^{2=}$ .285, p< .001
	Complexity x Group	F (1,33) =30.659, $\eta^{2=}$ .489, p< .000
	Blocking x Complexity x Group	F (1,33) =5.556, $\eta^{2=}$ .148, p< .025

Individual data for all participants in both groups for all three variables (accuracy, reaction time, and word duration) can be seen in the Appendix 3.1.

3.7.1 Analysis of Accuracy

The between group ANOVA analysis revealed a main effect of Group (F (1,33) =14.180, $\eta^{2=}$ .307, p< .001), that is overall HC presented an average of 16% higher accuracy scores in total ($M_{accuracy}$= 181.35, SD= 9.45, percentage= 91%) as compared to the PWA ($M_{accuracy}$= 150.58, SD= 49.11, percentage= 75%). There was a main effect of Articulatory Complexity (F (1,33) =11.375, $\eta^{2=}$ .262, p< .002) where accuracy was reduced on complex words compared to simple ones ($M_{complex\ accuracy}$= 75.9%, $M_{simple\ accuracy}$= 82.3%). As Table 3.14 above shows, there was no effect of semantic blocking, and no other two-way or three-way interactions for accuracy.

3.7.2 Analysis of Reaction Time

The between subject's ANOVA analysis revealed a main effect of Group (F (1, 33) = 439.63, n^2= .932, p= .000), that is HC reaction times were 815 ms shorter (M_{RT} = 770.67, SD= 65.92) as compared to the PWA (M_{RT} = 1585.99, SD= 455.56).

Additionally, a main effect of Blocking (F (1,33) =39.466, $\eta^{2=}$ .552, p< .000) was observed. Words in the heterogeneous conditions were 192 ms faster to be named (M_{hetero}= 1078.20, SD_{hetero}= 452.35) than when the same words were displayed in the homogenous conditions (M_{homo}= 1270.69, SD_{homo}=601.77). A main effect of Complexity (F (1,33) =13.241, $\eta^{2=}$ .293, p< .001) was also found, where reaction times on simple words were 150 ms shorter (M_{simple}= 1100.48, SD_{simple}= 454.45) than on complex words ($M_{complex}$= 1250.56, $SD_{complex}$= 615.62). The main effects can be seen in Figure 3.2 above.

A two-way interaction was shown between semantic Blocking and Group (F (1,33) =20.162, $\eta^{2=}$ .387, p< .000). A subsequent one-way within group ANOVA found that the reaction times for both the PWA (F (1,17) = 30.080, $\eta^{2=}$ .653, p< .000) and the HC (F (1,17) = 22.594, $\eta^{2=}$ .585, p< .000) were significantly affected by the blocking conditions. However, the blocking condition affected the PWA considerably, with words averaging 380 ms longer in the homogenous condition (M_{hetero}= 1363.19, SD_{hetero}=423.77; M_{homo}= 1742.90, SD_{homo}= 513.81) compared to the differences in reaction time between the two blocking conditions (55 ms longer in the homogenous conditions) for the HC (M_{hetero}=742.73, SD_{hetero}= 62.38 ;,M_{homo}=797.19, SD_{homo}= 76.14) as depicted in Figure 3.4 below.

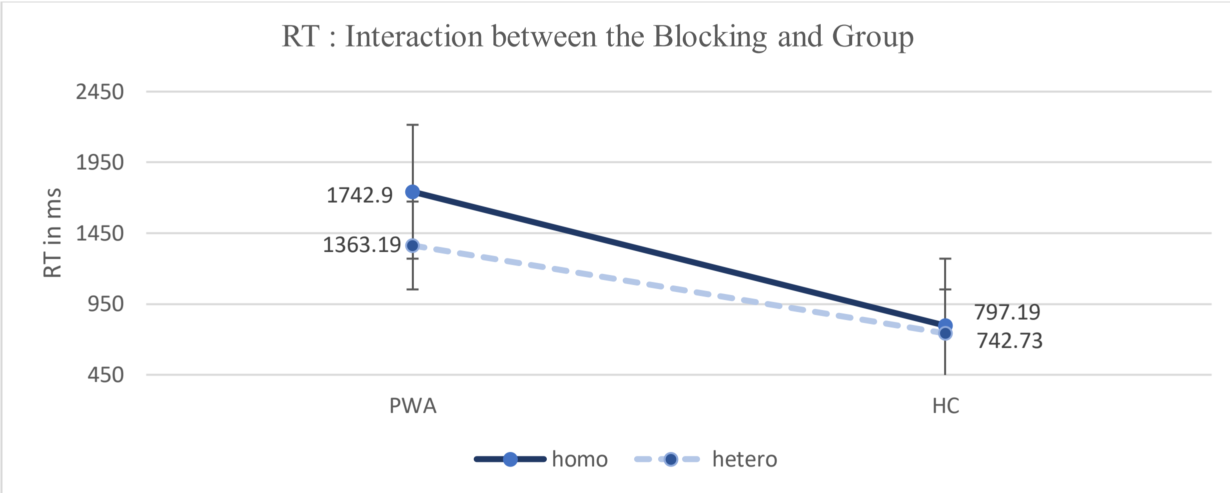


Figure 3.4 Interaction between the blocking Condition and Group for the mean scores in the reaction time analysis for the PWA and the HC.

Another two-way interaction between Complexity and Group ($F (1,33) = 6.831$, η^{2}= .176, $p < .014$) was found. As observed in the further analysis from the one-way within group ANOVA, reaction times were significantly longer on complex words (239.2 ms longer) compared to simple words for the PWA ($F (1,17) = 12.405$, η^{2}= .437, $p < .003$; M_{simple}= 1471.15, SD_{simple}= 383.57; $M_{complex}$ = 1710.37, $SD_{complex}$ = 571.56). This significant difference is not as evident in the HC ($F (1,17) = 9.984$, η^{2}= .384, $p < .006$; M_{simple}=750.86, SD_{simple}= 64.56; $M_{complex}$ = 790.76, $SD_{complex}$ = 75.51) where the difference in reaction times between complex and simple words was 39.9 ms. The interaction can be seen in the Figure 3.5 below. No other two-way or three-way interactions were found.

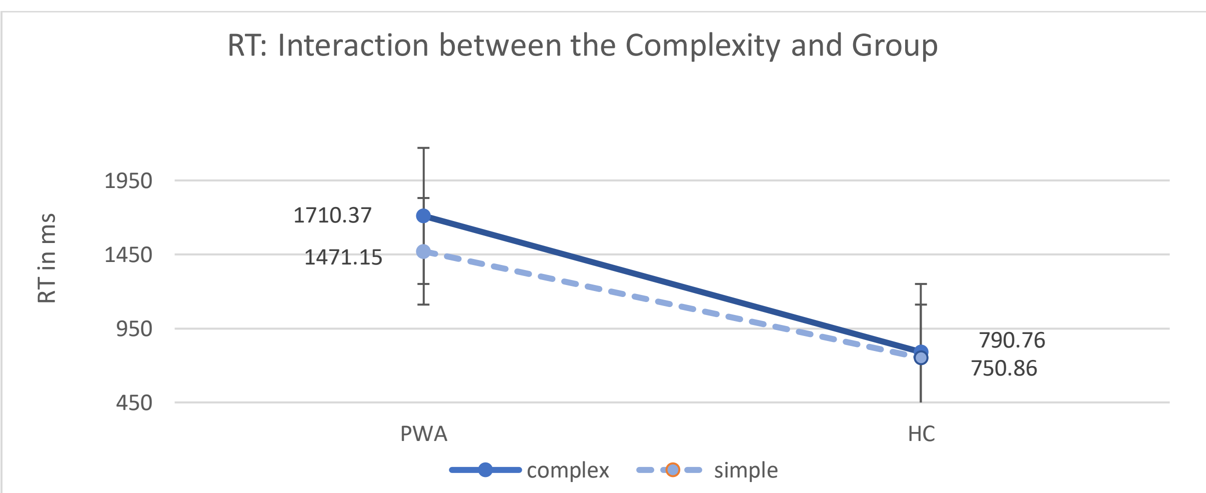


Figure 3.5 Interaction between the articulatory Complexity and Group for the mean score in the reaction time analysis for the PWA and HC.

3.7.3 Analysis of Word Duration

The between subject's ANOVA analysis revealed a Group effect, specifically, overall HC WD were 109 ms shorter (M= 489.03, SD= 115.38) as compared to the PWA (M= 599.28, SD= 196.03). Additionally, a main effect of Blocking (F (1,33) =79.071, p< .000) was also found (M_{hetero}= 523.94, SD_{hetero}= 89.82; M_{homo}= 562.45, SD_{homo}= 102.07). That is, WD were significantly longer in the homogenous conditions compared to the heterogeneous conditions, with a difference of 39 ms.

A main effect of Complexity (F (1,33) =181.97, p< .000) was also found where complex words required an average of 103 ms more to articulate ($M_{complex}$= 596.71, $SD_{complex}$= 121.22) than words that were considered simple (M_{simple}= 493.07, SD_{simple}= 76.24).

A two-way interaction between Blocking and Complexity (F (1,33) =6.592, p< .015) was found, where complex words in both the homogenous ($M_{homo\text{-}complex}$= 620.624, $SD_{homo\text{-}complex}$= 138.894) and the heterogeneous conditions ($M_{hetero\text{-}complex}$= 572.685, $SD_{hetero\text{-}complex}$= 111.174) required an average of 207 ms longer to articulate than the simple words in both conditions ($M_{homo\text{-}simple}$= 508.386, $SD_{homo\text{-}simple}$= 80.627; $M_{hetero\text{-}simple}$= 477.105, $SD_{hetero\text{-}simple}$= 72.718).

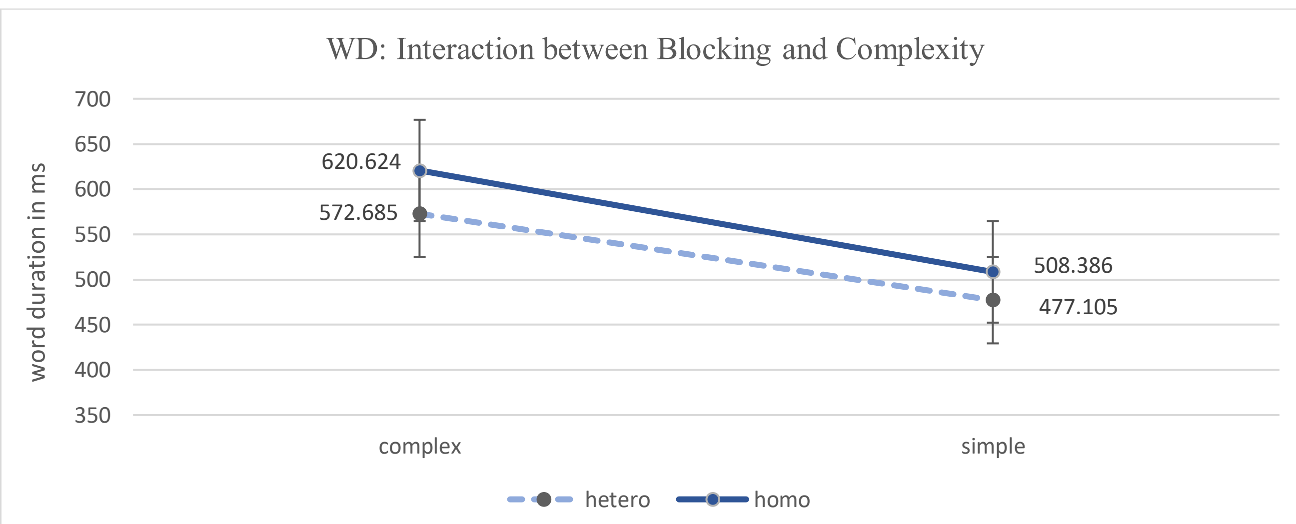


Figure 3.6 Interaction between the Blocking Condition and the Articulatory Complexity of words for the mean scores in the word duration analysis.

Additionally, a two-way interaction between Blocking and Group (F (1,33) =12.768, p< .001) was found. A one-way within group ANOVA was conducted to further investigate the interaction, which indicated that the word durations for both groups, PWA ($F(1,17) = 31.579$, $\eta^{2} = .664$, $p < .000$) and HC ($F(1,17) = 8.432$, $\eta^{2} = .345$, $p < .010$), were significantly affected by the Blocking condition. However, it was also evident that the PWA required a significantly longer amount of time to articulate words in both the homogenous and the heterogeneous conditions ($M_{hetero} = 572.301$, $SD_{hetero} = 94.229$; $M_{homo} = 627.943$, $SD_{homo} = 99.350$). This effect is also significant in the HC but not substantial ($M_{hetero} = 477.489$, $SD_{hetero} = 55.968$; $M_{homo} = 501.066$, $SD_{homo} = 501.29$). This interaction can be seen in Figure 3.7 below.

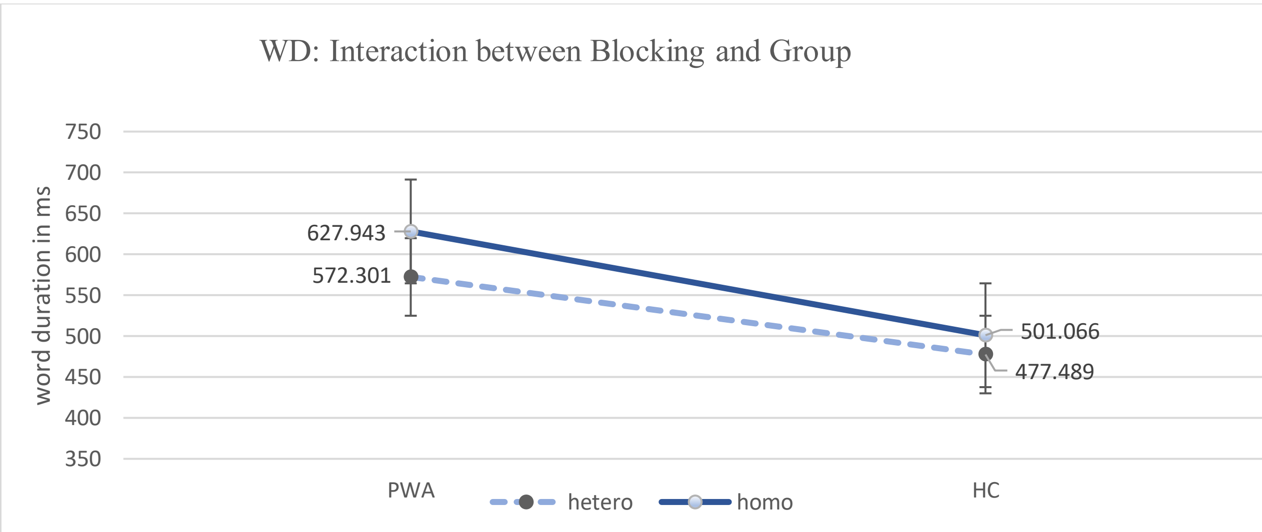


Figure 3.7 Interaction between the blocking Condition and Group for the mean scores in the word duration analysis for the PWA and HC.

Lastly, a two-way interaction between Complexity and Group ($F(1,33) = 30.659$, $p < .000$) was also observed. Further analysis revealed that both the PWA ($F(1,17) = 89.998$, $\eta^{2} = .849$, $p < .000$) and the HC ($F(1,17) = 238.403$, $\eta^{2} = .937$, $p < .000$) required a significantly longer amount of time to articulate complex words as compared to simple ones. However, the significance is more palpable in the PWA ($M_{simple} = 526.785$, $SD_{simple} = 80.03$; $M_{complex} = 673.459$, $SD_{complex} = 118.819$) with complex words requiring 55 ms more to articulate. With regards to HC ($M_{simple} = 458.706$, $SD_{simple} = 55.61$; $M_{complex} = 519.849$, $SD_{complex} = 60.480$) the difference between the complex and simple words was 24 ms. This interaction can be seen in Figure 3.8 below.

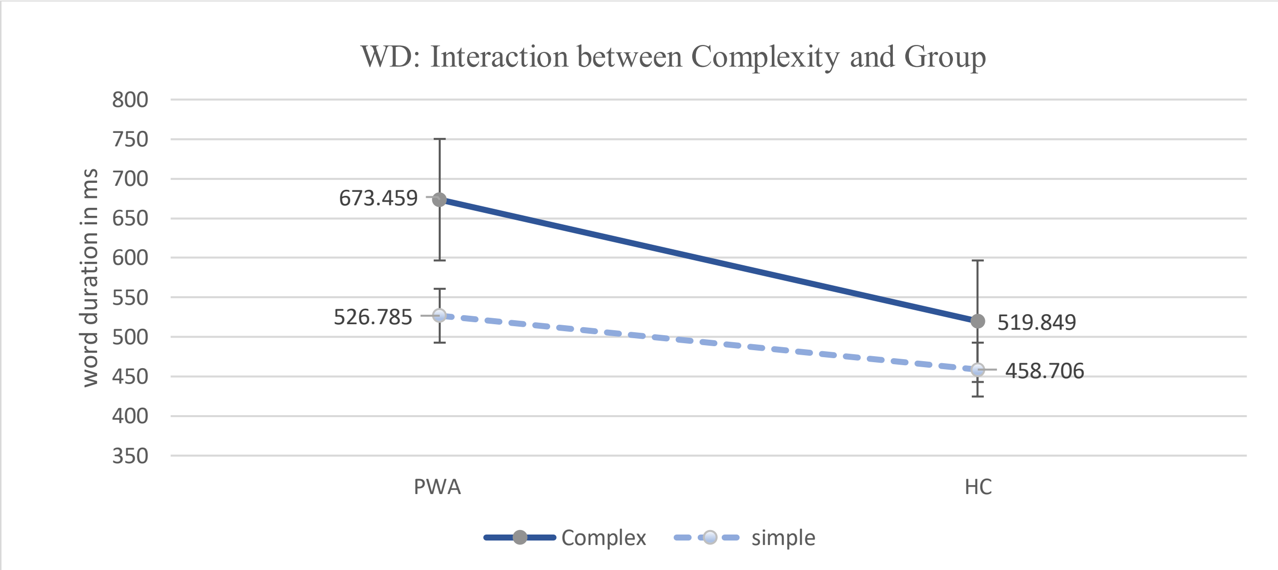


Figure 3.8 Interaction between the Articulatory Complexity and Group for the mean scores during the word duration analysis for the PWA and HC.

A three-way interaction between Blocking, Complexity, and Group ($F(1,33) = 5.556$, $p<$ .025) was observed. To identify the source of the three-way interaction, a two-way ANOVA was performed to measure the interaction between Blocking, Complexity, and Group for the HC and PWA separately. The results indicated that PWA have significantly longer words durations on complex words in the homogenous and heterogeneous conditions as compared to simple words in both conditions ($F(1,17) = 49.005$, $\eta^{2=}$ .754, $p< .000$) than the HC ($F(1,17) = .116$, $\eta^{2=}$ .007 $p<$ .738). This significant difference between the HC and PWA can be seen in Figure 3.3 above. Statistical results with main effects and interactions can be seen in Table 3.15 above.

3.7.4 Subsequent Analysis (Fluent vs Non- fluent PWA)

A subsequent analysis of the data was further carried out in order to compare accuracy, RT, and WD between the two classifications of aphasia: fluent and non-fluent. Following the analysis conducted previously, a one-way between repeated measures analysis of variance (ANOVA) was performed on the PWA. As in the previous section, between subjects ANOVA between the 8 fluent (DT, WM, CM, PS, HF, CW, BH, NH) and 9 non-fluent (CB, RB, IB, CD, RR, SA, PW, CB-2, EM) PWA was further conducted to investigate the interactions found.

Descriptive statistics for the fluent and non-fluent PWA can be seen in Table 3.15, 3.16, and 3.17 below.

Table 3.15 : *Descriptive Statistics for Fluent and Non-fluent people with aphasia on the blocked non-cyclical naming task*

Fluent People with Aphasia N=8				Non-fluent People with Aphasia N=9			
Accuracy							
Homogenous		**Heterogeneous**		**Homogenous**		**Heterogeneous**	
Simple	40.14 (10.14)	Simple	39.00 (12.62)	Simple	35.90 (9.78)	Simple	35.30 (8.72)
Complex	39.86 (10.79)	Complex	38.43 (13.07)	Complex	35.30 (8.72)	Complex	32.60 (6.67)
Total (n=100 in each condition)				Total (n=100 in each condition)			
74.56 (19.25)		73.78 (23.63)		73.875 (15.86)		66.625 (13.32)	
Overall mean accuracy for both conditions (n=200)				Overall mean accuracy for both conditions (n=200)			
148.33 (42.53)				140.50 (28.84)			
74%				70%			
Reaction time (RT)							
Homogenous		**Heterogeneous**		**Homogenous**		**Heterogeneous**	
Simple	1316.90 (407.74)	Simple	1082.07 (128.71)	Simple	1818.74 (344.52)	Simple	1475.29 (365.44)
Complex	1469.78 (422.23)	Complex	1137.98 (154.69)	Complex	2171.70 (637.58)	Complex	1794.43 (522.22)
Total				Total			
1523.91 (548.98)		1272.622 (396.94)		1842.17 (394.12)		1470.84 (407.48)	
Overall mean reaction time in both conditions				Overall mean reaction time in both conditions			
1399.12 (473.35)				1658.16 (387.57)			
Word duration (WD)							
Homogenous		**Heterogeneous**		**Homogenous**		**Heterogeneous**	
Simple	550.41 (168.09)	Simple	584.24 (109.99)	Simple	564.44 (129.09)	Simple	509.37 (156.60)
Complex	682.29 (206.07)	Complex	617.29 (151.75)	Complex	729.92 (242.83)	Complex	657.42 (219.58)
Total				Total			
597.05 (69.21)		548.54 (57.53)		652.40 (120.68)		597.24 (120.81)	
Overall mean word duration in both conditions				Overall mean word duration in both conditions			
569.69 (61.26)				624.41 (120.68)			

Note: means are written with standard deviations in parenthesis.

Table 3.16 : *Results of the Statistical Analysis for the People with Aphasia.*

	Between Group Analysis	
	Condition	**Statistics Analysis**
Accuracy	Group	F (1,29) = .226, η^2= .015, p=.614
	Semantic blocking	F (1,29) = .588, $\eta^{2=}$ .217, p=.455
	Articulatory complexity	F (1,29) = 9.565, $\eta^{2=}$ .395, p< .007
	Blocking x Complexity	F (1,29) = .565, $\eta^{2=}$ .000, p=.464
	Blocking x Group	F (1,29) = 3.975, $\eta^{2=}$ .248, p=.065
	Complexity x Group	F (1,29) = 2.952, $\eta^{2=}$ .009, p=.106
	Blocking x Complexity x Group	F (1,29) =1.080, $\eta^{2=}$ .047, p=.315
Reaction Time (ms.)	Group	F (1, 29) = 243.52, n^2= .932, p< .016
	Semantic blocking	F (1,29) =28.513, $\eta^{2=}$ .564, p< .000
	Articulatory complexity	F (1,29) = 9.364, $\eta^{2=}$ .493, p< .008
	Blocking x Complexity	F (1,29) =12.431, $\eta^{2=}$ .991, p= .081
	Blocking x Group	F (1,29) =26.443, $\eta^{2=}$ .558, p= .016
	Complexity x Group	F (1,29) =12.431, $\eta^{2=}$ .991, p= .040
	Blocking x Complexity x Group	F (1,29) =6.980, $\eta^{2=}$ 0.342, p<.518
Word Duration (ms.)	Group	F (1,29) = 636.74, n^2= .348, p< .028
	Semantic blocking	F (1,29) =48.515, $\eta^{2=}$ .622, p< .000
	Articulatory complexity	F (1,29) =92.995, $\eta^{2=}$ .951, p< .000
	Blocking x Complexity	F (1,29) = 6.412, $\eta^{2=}$ .531, p< .023
	Blocking x Group	F (1,29) =.301, $\eta^{2=}$ .215, p= .539
	Complexity x Group	F (1,29) =9.396, η^2=12 .401, p= .042
	Blocking x Complexity x Group	F (1,29) =7.543, $\eta^{2=}$ .343, p< .015

Table 3.17: *Statistical Results for Eight Fluent and Nine Non-fluent people with Aphasia on the Blocked Non-cyclical Naming Task*

Fluent PWA N= 8 Condition	Fluent PWA N= 8 Statistics Analysis	Non-fluent PWA N= 9 Condition	Non-fluent PWA N= 9 Statistics Analysis
Accuracy			
Semantic blocking	F (1,7) =1.066, $\eta^{2=}$ .329, p= .106	Semantic blocking	F (1,10) =.513, $\eta^{2=}$ .079, p= .501
Articulatory complexity	F (1,7) =123.124, $\eta^{2=}$ .932, p< .000	Articulatory complexity	F (1,10) =.116, $\eta^{2=}$ .928, p< .000
Blocking x Complexity	F (1,7) =.630, $\eta^{2=}$ .065, p=.448	Blocking x Complexity	F (1,10) =2.542, $\eta^{2=}$ .298, p= .162
Reaction Time			
Semantic blocking	F (1,7) =15.334, $\eta^{2=}$ .719, p< .008	Semantic blocking	F (1,10) =14.066, $\eta^{2=}$ .610, p< .005
Articulatory complexity	F (1,7) =5.224, $\eta^{2=}$ .465, p= .062	Articulatory complexity	F (1,10) =5.256, $\eta^{2=}$ .369, p< .048
Blocking x Complexity	F (1,7) =3.017, $\eta^{2=}$ .335, p= .133	Blocking x Complexity	F (1,10) =.007, $\eta^{2=}$ .001, p= .935
Word Duration			
Semantic blocking	F (1,10) =12.438, $\eta^{2=}$ .675, p< .012	Semantic blocking	F (1,7) =45.365, $\eta^{2=}$ .834, p< .000
Articulatory complexity	F (1,7) =71.367, $\eta^{2=}$ .888, p<.000	Articulatory complexity	F (1,10) =41.722, $\eta^{2=}$ .874, p< .000
Blocking x Complexity	F (1,7) =1.469, $\eta^{2=}$ .140, p= .256	Blocking x Complexity	F (1,10) =6.530, $\eta^{2=}$ .521, p< .043

3.7.4.1 Accuracy. The between group ANOVA analysis revealed a main effect of Articulatory Complexity (F (1,29) = 9.565, p< .007) where accuracy was reduced on complex words compared to simple ones ($M_{complex\ accuracy}$= 70.1%, $M_{simple\ accuracy}$= 74.7%). Additionally, the within group ANOVA analysis for accuracy revealed only a main effect of complexity for both groups of aphasia with a result of (F (1,7) =123.124, *p*< .000) for the fluent PWA and a (F (1,10) =.116, *p*< .000) for the non-fluent PWA group. Both groups of PWA had more errors on complex words than simple words; however, the non-fluent PWA (M_{simple}= 73.80%, SD_{simple}= 15.33; $M_{complex}$ = 66.63%, $SD_{complex}$ =14.14) exhibited 8% more errors on complex words compared to the simple ones. The fluent PWA (M_{simple}= 74.78%, SD_{simple}= 24.32; $M_{complex}$ = 73.33%, $SD_{complex}$ = 24.305) exhibited 1% more errors on complex words in comparison to the simple ones. No other main effects or interactions were found.

3.7.4.2 Reaction time analysis. The between subjects ANOVA analysis revealed a main effect of Group (F (1, 29) = 243.52, p< .016), that is fluent PWA reaction times were 258 ms shorter (M_{RT} = 1399.12, SD= 473.35) as compared to the non-fluent PWA (M_{RT} = 1658.16, SD= 387.57).

Additionally, a main effect of Blocking (F (1,29) =28.513, p< .000) was also observed. Words were named 379 ms faster in the heterogeneous conditions (M_{hetero}= 1363.19, SD_{hetero}= 423.77) than when the same words were displayed in the homogenous conditions (M_{homo}= 1742.90, SD_{homo}= 513.81). A main effect of Complexity (F (1,29) = 9.364, p< .008) was also found, where reaction times on simple words were 243 ms shorter (M_{simple}= 1471.1, SD_{simple}= 383.5) than the complex words ($M_{complex}$= 1714.9, $SD_{complex}$= 574.4). The main effects can be seen in Figure 3.16 above.

An interaction between blocking and group (F (1,29) =26.443, $\eta^{2=}$ .558, p= .016) was further analysed using a within group ANOVA where both groups presented with main effects of blocking: fluent PWA (F (1,7) =15.334, *p*< .008) and non-fluent PWA (F (1,10) =14.066, *p*< .005). Both groups of PWA required an increased amount of time to respond when pictures were depicted in the homogenous conditions as compared to the heterogeneous conditions. However, the non-fluent PWA (M_{hetero}= 1470.84, SD_{hetero}=407.479; M_{homo}= 1842.17, SD_{homo}= 394.12) demonstrated significantly longer RT's, requiring 372 ms longer to name words in the homogenous conditions than the heterogenous conditions. The fluent PWA required only 251 ms to name words in the homogenous conditions compared to the heterogenous conditions (M_{hetero}= 1272.62, SD_{hetero}=438.594; M_{homo}= 1523.92, SD_{homo}= 608.00).

Additionally, an interaction between complexity and group was indicated (F (1,29) =12.431, p= .040). A within group ANOVA indicated that the non-fluent group revealed a main effect of complexity (F (1,10) =5.256, *p*< .048). The non-fluent group required 358 ms longer to name the complex pictures ($M_{complex}$ = 1846.34, $SD_{complex}$ =588.277) than the simpler ones (M_{simple}= 1488.44, SD_{simple}= 242.82), and this statistical significance was not palpable in the fluent PWA.

3.7.4.3 Word duration analysis. The between subject's ANOVA analysis revealed a Group effect (F (1,29) = 636.74, p< .028), specifically, overall the WD of the fluent PWA were 55 ms shorter (M= 569.69, SD= 61.26) as compared to the non-fluent PWA (M= 624.41, SD= 120.68). Additionally, a main effect of Blocking (F (1,29) =48.515, p< .000) was also indicated

(M_{hetero}= 572.42, SD_{hetero}= 179.22; M_{homo}= 625.78, SD_{homo}= 208.01). That is, WD were significantly longer in the homogenous conditions as compared to the heterogeneous conditions with a difference of 53 ms. A main effect of Complexity ($F(1,29) = 92.995$, $p < .000$) was also found where complex words required an average 101.6 ms more to articulate ($M_{complex}$= 673.8, $SD_{complex}$= 118.8) than words that were considered simple (M_{simple}= 572.2, SD_{simple}= 673.8).

The within group ANOVA analysis for the WD's of both the fluent and non-fluent PWA revealed an effect of blocking: fluent PWA ($F(1,10) = 12.438$, $p < .012$) and non-fluent PWA ($F(1,7) = 45.365$, $p < .000$). Both groups of PWA required more time to articulate words in the homogenous condition as compared to the heterogeneous conditions with the word durations of the non-fluent PWA (M_{hetero}= 597.34, SD_{hetero}=114.720; M_{homo}= 652.04, SD_{homo}= 116.80) being more effected by the Blocking condition than those with fluent aphasia (M_{hetero}= 548.51, SD_{hetero}=57.526; M_{homo}= 597.06, SD_{homo}= 69.330). The non-fluent PWA required 55 ms more to articulate words in the homogenous condition as compared to the heterogenous conditions, whereas the difference in word durations for both conditions was 49 ms for the fluent PWA.

Moreover, a two- way interaction between Complexity and Group ($F(1,29) = 9.396$, $p = .042$) was further analyzed using a within group ANOVA which revealed: fluent PWA ($F(1,7) = 71.367$, $p < .000$) and non-fluent PWA ($F(1,10) = 41.722$, $p < .000$) with the difference being 150 ms between the word duration in the naming of the complex words being significantly larger than that of naming the simple words for the non-fluent PWA ($M_{complex}$ = 648.82, $SD_{complex}$ =56.512; M_{simple}= 498.03, SD_{simple}= 67.38) and 138 ms for the fluent PWA ($M_{complex}$ = 694.10, $SD_{complex}$ =154.273; M_{simple}= 556.11, SD_{simple}= 84.24).

Furthermore, a two-way interaction between Blocking and Complexity ($F(1,29) = 6.412$, $p < .023$) was found. Where complex words in both the homogenous ($M_{homo\text{-}complex}$= 709.27, $SD_{homo\text{-}complex}$= 128.20) and the heterogeneous conditions ($M_{hetero\text{-}complex}$= 637.64, $SD_{hetero\text{-}complex}$= 113.83) required an average 71 ms longer time to articulate than the simple words in both conditions ($M_{homo\text{-}simple}$= 546.61, $SD_{homo\text{-}simple}$= 83.01; $M_{hetero\text{-}simple}$= 509.96, $SD_{hetero\text{-}simple}$= 78.11).

Lastly, a three- way interaction between Blocking, Complexity, and Group (F (1,29) =7.543, p< .015) was observed. To identify the source of the three-way interaction, a two-way ANOVA was performed. An interaction between blocking and complexity was only found in the non-fluent group with aphasia (F (1,10) =6.530, *p*<.043). The word duration for the complex words in both the homogenous ($M_{homo\text{-}complex}$= 686.06, $SD_{homo\text{-}complex}$= 73.89) and the heterogeneous conditions ($M_{hetero\text{-}complex}$= 571.28, $SD_{hetero\text{-}complex}$= 72.86) required longer time to articulate than the simple words in the same conditions ($M_{homo\text{-}simple}$= 611.15, $SD_{homo\text{-}simple}$= 49.66; $M_{hetero\text{-}simple}$= 478.32, $SD_{hetero\text{-}simple}$= 63.84). This interaction can be seen in Figure 3.9 below.

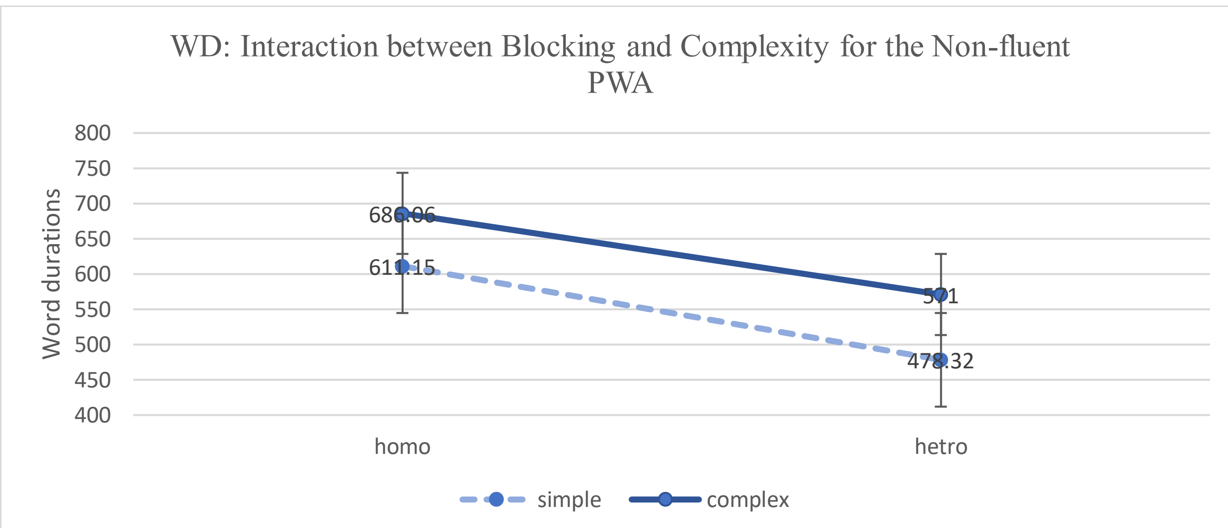


Figure 3.9 Interaction between the blocking and word complexity on word duration analysis for the non-fluent PWA.

3.7.5 Subsequent Analysis (Individual Level Analysis)

On the individual level analysis (see Table 3.17), not all PWA exhibited the Blocking effect nor the Complexity effect on the reaction time analysis. Thirteen of the seventeen participant's reaction times were significantly affected by the Blocking condition. Three of the four participants not affected by the blocking condition (DT, HF, and IB) were fluent PWA, had a high Aphasia Quotient, and excelled in their background linguistic measures. Moreover, those same three individuals with aphasia whom were not affected by the Blocking condition and were also not effected by complexity as well. Individual level analysis for reaction times on

Complexity exhibited diverse results where only four PWA's reaction times were significantly affected by the complexity of word.

On the other hand, on the individual level analysis for word duration's it was apparent that regardless of the diagnosis of aphasia (whether it was mild, moderate, or severe) or the diagnosis of apraxia, most participants with aphasia were significantly affected by the blocking condition (except for HF, PW, and WM) and all the PWA's word durations were significantly affected by the complexity of the word.

Table 3.17: *Individual Level Analysis on Blocking Conditions and Complexity*

	Aphasia Type	AQ	Apraxia of Speech	Reaction Time		Word Duration	
				Blocking	Complexity	Blocking	Complexity
DT	Anomia	90.2	X	t (45)= -1.765, p= .084	t (88)= -.233, p= 816	t (45)= -4.029, p<.000	t (69) = 5.713, p< .000
CB	Broca	56.8	✓	t (56) = -2.247, p< 0.29	t (75) – 1.152, p= .253	t (56),= -3 .832, p<.000	t (76)= 7.512, p< .000
WM	Conduction	77.8	✓	t (65)= -2.607, p<.011	t (89) = 1.457, p= .149	t (65) = -1.749, p=.085	t (89) = 6.298, p<.000
RB	Broca	62.4	✓	t (46) = -2.096, p< .042	t (78)= .970. p= .335	t (46)= -2.059, p<..045	t (79) = 6.387, p< .000
IB	TCM	92.8	✓	t (65)= -1.905, p= .061	t (82) = .280, p=.780	t (65)= -2.703, p<.009	t (82) = 5.885, p < .000
CD	Broca	59.6	✓	t (46)= - 2.194, p< .033	t (84)= 7.860, p<.000	t (46)= -2.287, p<.027	t (84) = - 7.447, p<.000
CM	Anomia	93.6	X	t (93)= -2.165, p<.002	t (97)= 3.3-2, p< .001	t (93) = -2.332, p<.022	t (95)= 5.250, p< .000
RR	Broca	69.6	X	t (68)= -5.445, p< .000	t (86)= 6.231, p< .000	t (68)= 4.493, p<.000	t (86) = 5.107, p< .000
SA	Anomia	86	✓	t (81) = -3.156, p< .002	t (89)= 2.242, p< .027	t (82) = -2.844, p< .006	t (88) – 5.038, p< .000
PW	Broca	74.6	✓	t (71) = 2.167, p<.034	t (87)= .388, p= .699	t (71)= -1.534, p=.130	t (88) = 4.786, p < .000
CB-2	Broca	58.6	✓	t (27)= -5.098, p< .000	t (53) = .304, p= .762	t (26)= -5.547, p<.000	t (53)= 3.262, p<. 002
PS	Conduction	83.6	✓	t (21)= -4.077, p< .001	t (47)= 1.143, p= .256	t (22)= -2.138, p<.044	t (47) = 4.095, p< .000
HF	Anomia	94.4	X	t (94)= -.609, p= .544	t (97) = .009, p= 993	t (94)= -.363, p= .718	t (97) = 3.990, p<.000
EM	TCM	72.2	✓	t (82)= -3.624, p<.001	t (92) = .846, p=.400	t (82)= -4.754, p<.000	t (92) = 3.146, p< .002
CW	Conduction	72.9	✓	t (17)= -.749, p= .464	t (56)= 2.509, p=0.15	t (17)= -5.749, p< .000	t (56) = 2.509, p<. 015
BH	Anomia	89.4	X	t (89) = -2.805, p< .006	t (94) = 1.799, p= .075	t (87) = -3.186, p<.002	t (95)= 2.857. p< .005
NH	Anomia	94.2	✓	t (77)= -2.359, p< .021	t (86) = .015, p=.988	t (77)= -2.840, p<.006	t (87) = 4.417, p< .000

3.7.6 Repetition Control Task Results

As mentioned previously, repetition was implemented as a control task using the same stimuli as for the naming task and requiring the participants to repeat the stimuli heard. As repetition ordinarily takes advantage of the phonological step of the lexical access while surpassing the semantic step, we assume there should be no influence from semantic blocking on the repetition task as compared to the naming task (see Table 3.18 below). Correspondingly, as indicated in Table 3.18 below, only two interactions were found between articulatory complexity and group, both on the accuracy and word durations. The PWA participants exhibited more errors and longer word durations on words that were considered complex compared to the HC. The main effects of articulatory complexity on all three variables (accuracy, RT, and WD) would be inconclusive because the effect of articulatory complexity could be a generalised deficit resulting from an impaired articulatory system.

Table 3.18: *Main effects and interactions for the people with aphasia and healthy controls on the repetition control task*

Naming statistical analysis		*Repetition statistical analysis*	
Accuracy			
Group	F (1, 33) = 14.180, n^2= .307, p<.001	Group	f (1, 33) = .055, n^2= .002, p= .816
Semantic blocking	F (1,33) = 1.424, η^2= .041, p=.241	Semantic blocking	f (1, 33) = .139, n^2= .004, p= .713
Articulatory complexity	F (1,33) =11.375, η^2= .262, p< .002	Articulatory complexity	f (1, 33) = 11.502, n^2= .264, p< .002
Blocking x Complexity	F (1,33) = .013, η^2= .000, p=.910	Blocking x complexity	f (1, 33) = 13.478, n^2= .001, p= .926
Blocking x Group	F (1,33) = .013, η^2= .000, p=.910	Blocking x group	f (1, 33) = .270, n^2= .008, p= .607
Complexity x Group	F (1,33) = 2.036, η^2= .000, p=.945	Complexity x group	f (1, 33) = 7.897, n^2= .198, p< .008
Blocking x Complexity x Group	F (1,330 =1.584, η^2= .047, p=.217	Blocking x complexity x group	f (1, 33) = 9.638, n^2= .231, p= .004
Reaction Time (ms.)			
Group	F(1, 33) = 439.63, n^2= .932, p<..000	Group	f (1, 33) = 6.606, n^2= .171, p< .015
Semantic blocking	F (1,33) =39.466, η^2= .552, p< .000	Semantic blocking	f (1, 33) = 329.06, n^2= .005, p= .685
Articulatory complexity	F (1,33) =13.241, η^2= .293, p< .001	Articulatory complexity	f (1, 33) = 4967.22, n^2= .452, p< .000
Blocking x Complexity	F (1,33) =2.799, η^2= .080, p= .104	Blocking x complexity	f (1, 33) = 1012.05, n^2= .25, p= .816
Blocking x Group	F (1,33) =20.162, η^2= .387, p< .000	Blocking x Group	f (1, 33) = 489.04, n^2= .008, p= .621
Complexity x Group	F (1,33) =6.831, η^2= .176, p< .014	Complexity x Group	f (1, 33) = 1918.07, n^2= .031, p= .320
Blocking x Complexity x Group	F (1,33) =.230, η^2= .007, p=.634	Blocking x complexity x group	f (1, 33) = 197.67, n^2= .007, p= .644
Word Duration (ms.)			
Group	F (1, 33) = 1606.84, n^2= .980, p<.000	Group	f (1, 33) = 4.796, n^2= .130, p< .036
Semantic blocking	F (1,33) =79.071, η^2= .712, p< .000	Semantic blocking	f (1, 33) = 009, n^2= .000, p= .923
Articulatory complexity	F (1,33) =181.967, η^2= .850, p< .000	Articulatory complexity	f (1, 33) = 183.843, n^2= .852, p< .000
Blocking x Complexity	F (1,33) =6.592, η^2= .171, p< .015	Blocking x complexity	f (1, 33) = .071, n^2= .002, p= .792
Blocking x Group	F (1,33) =12.768, η^2= .285, p< .001	Blocking x Group	f (1, 33) = 1.133, n^2= .034, p= .295
Complexity x Group	F (1,33) =30.659, η^2= .489, p< .000	Complexity x Group	f (1, 33) = 6.295, n^2= .164, p< .017
Blocking x Complexity x Group	F (1,33) =5.556, η^2= .148, p< .025	Blocking x complexity x group	f (1, 33) = 14.613, n^2= .033, p= .776

3.8 Discussion

As discussed previously, in most PWA, both linguistic and speech motor abilities are compromised (Blumstein, 2001; Kurowski et al., 2007; McNeil & Kent, 1990). Consequently, it is vital to recognise the possible influences of both the linguistic and speech motor processes and the potential interactions amongst them. Therefore, the present study set out to determine the interaction between linguistic and speech motor processes in PWA and age and education HC. The use of a wide range of variables – accuracy, RT's, and WD's – were implemented to measure the interaction between linguistic and speech motor processes on a picture-naming task using stimuli in different semantic contexts (homogenous vs heterogeneous) with varying articulatory complexity (simple vs complex). An overall summary for the main findings for all three variables can be seen in Table 3.19 below.

Table 3.19: *Overall summary of the Results of the Current Study on PWA and HC*

	Parameters	**Findings**	**$\eta^{2=}$**	**p**
Accuracy	Group	✓ (PWA >HC)	.307	<.001
	Semantic blocking	X	.041	.410
	Articulatory complexity	✓ (Si > Co)	.262	<.002
	Blocking x Complexity	X	.000	.910
	Blocking x Group	X	.001	.900
	Complexity x Group	X	.000	.945
	Blocking x Complexity x Group	X	.047	.217
RT	Group	✓ (PWA >HC)	.932	<.000
	Semantic blocking	✓ (Ho > Ht)	.532	<.000
	Articulatory complexity	✓ (Co > Si)	.293	<.001
	Blocking x Complexity	X	.808	.104
	Blocking x Group	✓ PWA (Δ Ho- Ht) > HC (Δ Ho- Ht)	.387	<.000
	Complexity x Group	✓ PWA (Δ Co-Si) > Hc(Δ Co-Si)	.176	<.014
	Blocking x Complexity x Group	X	.007	.634
WD	Group	✓ (PWA >HC)	.980	<.000
	Semantic blocking	✓ (Ho > Ht)	.712	<.000
	Articulatory complexity	✓ (Co > Si)	.850	<.000
	Blocking x Complexity	✓ (Ho+Co> Ht+Co)	.171	<.015
	Blocking x Group	✓ PWA (Δ Ho- Ht) > HC (Δ Ho- Ht)	.285	<.001
	Complexity x Group	✓ PWA (Δ Co-Si) > Hc(Δ Co-Si)	.489	<.000
	Blocking x Complexity x Group	✓ PWA (Ho/Co) > Hc (Ho/Co)	.148	<.025

Note: ✓- significant finding, X- insignificant finding, Si- simple, Co- complex, Ho- homogenous, Ht- heterogeneous, Δ- difference

3.8.1 Effect of Aphasia Impairment

In line with our predictions, the PWA were significantly affected by manipulations of both the linguistic and speech motor processes. The manipulations of these processes instigated a reduction in naming accuracy and longer RT in comparison to HC. Our results build on those of previous studies that have investigated lexical access by using the semantic blocked paradigm while measuring accuracy and RT, providing more direct evidence that semantic interference is manifested in longer RT in the homogenous conditions for PWA (Jefferies & Lambon Ralph, 2006).

Corresponding to our results, in a case study on an individual with non-fluent aphasia, BM, Wilshire and McCarthy (2002) implemented the blocked cyclical picture-naming paradigm and their results indicated that BM exhibited a reduction of accuracy on the semantically blocked contexts where he produced more errors and showed great difficulty in selecting from highly activated competitors. Additionally, Biegler, Crowther, and Martin (2008) obtained comparable results of blocking effect when conducting a similar study on three people with aphasia and seven healthy older adults as controls. The study reports the effects of semantic blocking on both RTs and accuracy in the participants with aphasia, and only on RT in the healthy older adults. While the blocking effects for the healthy older controls and the participant with fluent aphasia were similar to one another, the effects of blocking on the participants with non-fluent aphasia were exaggerated with a larger difference in RT and accuracy in the homogenous conditions compared to the heterogeneous conditions.

Additionally, our results further demonstrated the influence of articulatory complexity on speech motor processing, where complex words required more time to name than those that were considered simple, with the PWA experiencing greater difficulty and presenting longer WD’s than the HC. Specifically, the effect of WD on the complex words highlights the notion that with greater speech motor demands, PWA require an increased amount of time to adjust their speech motor system to articulate the targeted word.

3.8.2 Manipulation of Linguistic Processes (Semantic Context)

Based on prior research on PWA and HC and the effect of linguistic manipulations (semantic, phonological, and syntactic) on RT (Belke et al., 2005; Schnur et al., 2006, 2009; Novick et al., 2009), we predicted that both PWA and HC would display an increase in RT’s in the semantically blocked contexts. Indeed, the manipulation of linguistic variables in this study induced longer RT's in the semantically blocked contexts (i.e., homogenous conditions). The effects of semantic contexts can be observed in both participant groups, PWA and HC, through longer RT's in the homogenous conditions during the naming task. Further, this supports previous studies on lexical access in both HC and PWA. The longer RT in the homogenous conditions corroborate the findings of Schnur et al. (2006), where both PWA and HC in their study exhibited a decrease in accuracy and longer RT's as a consequence of the manipulations of linguistic variables.

Additionally, similar to the findings in Chapter 2, manipulations of the linguistic variables induced longer WD's. Specifically, words in the semantically blocked contexts (homogenous conditions) influenced speech motor performance to produce longer WD's. This finding demonstrates that alterations to the linguistic levels extend and influence lower processing levels such as speech motor performance. More precisely, the effect of linguistic complexity on word duration highlights the notion that as linguistic demands increase, adjustments to the speech motor systems must accommodate those increases. As discussed previously in Chapter 2, this discovery is a unique and vital finding which extends the literature and word production models concerning the dynamic relationship between linguistic and speech motor processes as well as the influence they have on one another. As such, this study is the only study to measure and report longer WD in semantically blocked conditions.

As reviewed previously, prior studies documenting the effect of semantic manipulations on linguistic processing have commonly discussed that semantic interference is influenced by the increased activation of the semantic competitors in the homogenous conditions (Belke et al., 2005; Damian et al., 2001; Kroll & Stewart, 1994; Roelofs, 2003; Schnur et al., 2009). Importantly, previous research assumes that the semantic interference effect is situated at the lexical level; however, the results from both Chapter 2 and this current one provides evidence for the effect of semantic interference extending beyond linguistic levels of word production and influencing the speech motor execution of the targeted word.

Correspondingly, this influence of the linguistic manipulations (semantic contexts) on speech motor performance reflects the cascading effects of lexical activation and selection processes on speech motor execution. To elaborate, the effect of semantic interference cascades throughout the linguistic processes and influences processes downstream from lexical access - including articulation and speech motor performance. The results from our study substantiate previous studies where researchers attempted to establish a more complex relationship between speech motor performance and higher levels of linguistic processing (Baese- Berk & Goldrick, 2009; Frisch & Wright, 2002; Goldrick & Blumstein, 2006; McMillan, Corley & Lickley, 2009).

3.8.3 Manipulation of Speech Motor Processes (Articulatory Complexity)

Moreover, manipulations of speech motor processes, specifically the articulatory complexity of words, induced a decrease in naming accuracy and an increase to the WD of the complex words as compared to the simple ones. These results substantiate previous studies investigating the effects of vowel characteristics on articulatory execution in PWA (Adam, 2013; Baum, 1993; Ryalls, 1986). Similar to our results, Bose, Van Lieshout, and Square (2007) investigated the effect of word and bigram frequency on RT and WD in ten healthy adults and eight PWA where all the participants were asked to repeat monosyllabic words which varied in frequency (high or low) and bigram frequency (high or low). Their study revealed a significant influence of vowel characteristic (tense/lax) in the stimuli on WD. That is, words that included tense vowels (considered articulatory complex) required more time to articulate compared to lax vowels (considered articulatory simple) which were shorter in duration. In studies that have utilised the IPC system as a means of measurement for articulatory complexity, healthy and impaired participants experienced greater difficulty, decreased accuracy, and longer WD in the production of articulatory complex words (Howell, 2002; Howell, 2004; Howell & Au-Yeung, 2007).

Additionally, similar to our previous study (Chapter 2), participants' RT's were significantly affected by the manipulations of the speech motor processes. These results further show that there is indeed an influence of speech motor processes, as measured by the articulatory complexity of words, on linguistic processes where RT's were significantly longer. Furthermore, our finding is indicative of the dynamic relationship between the speech motor and linguistic processes, where linguistic planning and processing is directly influenced by articulatory variables. The results of this study and preceding ageing studies suggest that linguistic planning such as lexical access, phonological encoding, and speech preparations were influenced by the complexity of words which led to longer RT (Howell, 2011). Therefore, it is evident that speech motor execution does not occur independently; rather, there is a direct and cascading association with linguistic processes (Bose et al., 2007, 2011). This distinct finding depicts the cascading relationship between linguistic and speech processes as the information from the sub-lexical levels (speech motor execution) impacting the higher levels of processing (linguistic processing and planning), providing additional evidence to support established cascaded models of lexical access (Caramazza, 1997; Costa et al., 2000; Cutting & Ferreira, 1999; Dell, 1986; Dell et al., 1997; Dell & O'Seaghdha, 1991). Although this finding was similar to that of our previous study, it is still distinctive as WD measures have not been used as a means of investigating speech motor processes during naming in PWA.

3.8.4 Interaction of Linguistic and Speech Motor Processes

Furthermore, an interaction between the linguistic and speech motor processes, as in blocking condition and articulatory complexity, was detected in this study. This interaction was exhibited by longer WD for complex words in the semantically blocked homogenous condition when compared to the same words in the heterogeneous conditions. Specifically, this interaction was detected for WD rather than RT, which is indicative that the interaction between linguistic and speech motor processes was occurring at the speech motor level rather than the lexical/semantic processing level. In addition, it is crucial to report that a further finding was identified, which determined that the PWA were the ones driving this interaction. No such interaction was reported in Chapter 2 between the healthy younger and healthy older adults. Therefore, this explicitly supports the notion that the interaction between the linguistic and speech motor processes only becomes evident in individuals with impairments to their speech motor systems, such as aphasia.

Moreover, this interaction further supports the previously discussed empirical studies that illustrate significant effects of linguistic features on word articulation and articulatory features on linguistic processing (Smith & Goffman, 2004). Those considerations point to a complex interplay of linguistic and speech motor processes in the production of words for PWA.

3.8.5 Fluent and Non-Fluent Aphasia

In the analysis of fluent and non-fluent PWA, accuracy data revealed similar results for both groups of PWA. Mutually, the fluent and non-fluent PWA displayed no main effects of blocking on accuracy. Britt, Ferrara, & Mirman (2016) found similar results in their study, where participants with fluent and non-fluent aphasia displayed the same error rates in the homogenous and heterogeneous conditions.

In regard to the manipulation of linguistic processes, we hypothesised that both groups with aphasia would display an effect of blocking, but the non-fluent PWA would require an increased amount of time to respond and name the targeted stimuli. As can be seen in Table 3.20 below, the non-fluent PWA exhibited longer RT in all four naming conditions, homogenous simple and complex as well as heterogeneous simple and complex, when compared to the fluent PWA. This aligns with a number of chronometric studies that have measured RT differences in fluent and non-fluent PWA using the semantic blocking paradigm (McCarthy & Kartsounis, 2000; Robinson, Shallice & Cipolotti, 2005; Schnur et al., 2005; Schnur et al., 2006; Wiltshire & McCarthy, 2002). In a 2005 study by Schnur and colleagues, results indicated that both fluent and non-fluent PWA indeed exhibit a blocking effect on the homogenous conditions with longer reaction times. However, it was also revealed that the blocking effects manifested themselves in each of the groups differently. They attributed the effect of the semantic context manipulations on the fluent PWA to the disruption of semantic representations or lexical-to-semantic connections, whereas in the non-fluent PWA, it was attributed to the impairment in the mechanism of the suitable stimuli selection. Similarly, Wilshire and McCarthy (2002) credited the increasing semantic blocking effect for the non-fluent PWA to the over-activation of competitors in the homogenous condition.

An abundant amount of evidence has indicated that the speech of non-fluent PWA, depending on severity, is slow and halting with long pauses between words or phrases, and effortful (Mary-Louise Kean, 1977; Ogar et al., 2005). Therefore, we hypothesised that the manipulation of speech motor processes would affect both groups of PWA, with the non-fluent PWA requiring more time to produce words that were considered articulatory complex compared to the fluent PWA. As can be seen in Table 3.20 below, both groups of aphasia displayed main effects of semantic blocking and articulatory complexity where words that were in the homogenous conditions and words that were considered articulatory complex required an increased amount of time for production compared to words in the heterogeneous condition and words that were considered simple. Additionally, the non-fluent PWA exhibited an interaction between blocking and complexity, where complex words in the homogenous conditions effected longer word durations compared to the same words when presented in the heterogeneous conditions. Critically, our findings parallel those of previous studies that provided evidence indicative of the interaction of lexical processing and speech motor control in PWA (D'Ausilio et al., 2009; Hickok, 2009; Meister, Wilson, Deblieck, Wu, & Iacoboni, 2007; Wilson, Saygin, Sereno, & Iacoboni, 2004).

In a recent study by Harvey, Traut, and Middleton (2019), fifteen participants with aphasia (six fluent, nine non-fluent) were asked to name 615 pictures from homogenous and heterogeneous categories in order to measure the effect of semantic interference on error types. Results of their study revealed effects of semantic interference that were evident in accuracy and reaction time analysis. The participants exhibited significant semantic interference, reflected by an increase in errors and longer reaction times in the homogenous conditions. Moreover, semantic interference was manifested in an increase of semantic errors, especially in the homogenous conditions.

Table 3.20: *Overall summary of the Results of the Current Study on Fluent and Non-Fluent PWA*

Fluent PWA		Non-fluent PWA	
Parameters	**Findings**	**Parameters**	**Findings**
Accuracy		**Accuracy**	
Semantic blocking	X	Semantic blocking	X
Articulatory complexity	✓ (Si > Co)	Articulatory complexity	✓ (Si > Co)
Blocking x complexity	X	Blocking x complexity	X
RT		**RT**	
Semantic blocking	✓ (Ho > Ht)	Semantic blocking	✓ (Ho > Ht)
Articulatory Complexity	X	Articulatory complexity	✓ (Co > Si)
Blocking x Complexity	X	Blocking x Complexity	X
WD		**WD**	
Semantic blocking	✓ (Ho > Ht)	Semantic blocking	✓ (Ho > Ht)
Articulatory complexity	✓ (Co > Si)	Articulatory complexity	✓ (Co > Si)
Blocking x Complexity	X	Blocking x complexity	✓ (Ho+Co> HtCo)

Note: ✓- significant finding, X- insignificant finding, Si- simple, Co- complex, Ho- homogenous, Ht- heterogeneous

3.8.6 Individual Analysis (PWA)

As previous research has indicated, individuals with aphasia exhibit extreme heterogeneous patterns in regard to performance in language, cognitive, and speech motor functions (Bose & Schafer, 2017; Helm-Estabrooks, 2002; Hoffman et al., 2009; Lambon

Ralph et al., 2010; Nicholas et al., 2011). These studies have reported that PWA exhibited specific results and individual case studies detected further differences.
In this study, as a group, PWA demonstrated significant effects in RT analysis for both naming words in semantically blocked conditions and for articulatory complex words. However, further investigation revealed that despite the identified significant results, there was a variation in the naming abilities among the individual participants with aphasia. Not all PWA were affected by the manipulations of linguistic processes. Out of the 17 PWA, the RT's of 4 PWA were not affected by blocking complexity and 13 were not affected by articulatory complexity.

Additionally, the PWA demonstrated significant effects of the manipulations of the speech motor processes with longer WD for naming both semantically blocked words and words considered articulatory complex. Individual level analysis revealed that regardless of the aphasia type, severity, and/or the presence of apraxia of speech, the WD of all PWA were affected in the speech motor execution of articulatory complex words. Furthermore, the WD's of all but three PWA were significantly affected by semantic context.

Therefore, as can be seen from our results, the PWA do demonstrate heterogeneous patterns in RT analysis and linguistic processing, where some PWA were sensitive to the linguistic manipulations and others were not. The results from our study furthermore indicate a vital finding in the area of speech motor performance and aphasia, in that articulatory execution was significantly affected by the manipulations of both linguistic and speech motor processes. This is suggestive of the need to conduct further investigations concerning speech motor processes in PWA, regardless of type and severity.

3.8.7 Conclusion

To conclude, the above results of the study provide additional support for the theory that speech motor execution of word production is not completely independent of linguistic processing. Furthermore, the influence of linguistic and speech motor performance on each other fits in with the growing body of literature from studies on healthy and impaired children and adults that have revealed significant associations between linguistic and speech motor processing. While the association between language and motor skills is well-documented in healthy children and adults as well as impaired children, more empirical work in the area of aphasia is necessary to expand our knowledge regarding this interaction.

The findings of the current study, in particular the interaction between speech motor and linguistic processes, are vital for both clinical and theoretical aspects in terms of word production in aphasia. This means that researchers and speech therapists must consider the influence and interaction of speech motor processes on linguistic processes in order to acquire a holistic view of word production deficits in aphasia. Additionally, taken together, the results of this study provide additional support for the 'cascading' models of spoken word production in which the manipulation of input at the lexical level led to increased changes at the speech motor level (Goldrick & Blumstein, 2006; Permunage, Blumestein, Myers, Goldrick & Baese-Berk, 2011).

Chapter 4

Measuring the Interaction of Linguistic, Speech Motor, and Executive Control Processes in Word Production in Healthy Younger and Healthy Older Adults

4.1 Abstract

Background:

A number of studies on language production have provided evidence for the importance of executive control mechanisms in the resolution of semantic interference during lexical access while naming. The individual influence of linguistic, speech motor, and executive control processes on word production in healthy young individuals has been with clear and robust interactions. However, research on the possible effect of healthy ageing on executive functioning abilities is sparse. Therefore, this present study aimed to further establish the effect of ageing on executive functioning abilities as well as the relationship amongst linguistic, speech motor, and executive control abilities in healthy younger and healthy older adults.

Aims:

This research had two aims: 1. To determine the difference between the performance of executive control measures between the healthy younger and healthy older adults. 2. To determine the relationship among the effect of semantic interference on the accuracy, RT (linguistic processes), and WD (speech motor performance) and executive control processes (inhibition, updating, shifting) in healthy younger and healthy older adults.

Methods:

Thirty healthy older adults (Mean= 74.0, SD= 8.71) and thirty healthy younger adults (Mean= 23.0, SD= 3.98) participated in the study. Tasks of inhibition included the word colour Stroop and the spatial Stroop. Tasks of updating of the working memory included the n-back and the forward and backward digit span. Additionally, the tasks measuring task switching included Trail Making Test and the same-different switching task. Correlations were calculated between the performance of the healthy younger and healthy older adults on the executive function tasks and their performance on the picture-naming task (effect of semantic interference on accuracy, RT, and WD).

Results:

Compared to the healthy younger adults, the healthy older adults demonstrated lower accuracy scores and were significantly slower on tasks that were timed (i.e., RT in spatial Stroop and performance time in the Trail Making Task). The healthy older adults

demonstrated positive correlations between measures of inhibition (word color Stroop and spatial Stroop) and the effect of semantic interference on both RT and WD during picture naming. They also showed a negative correlation on the backward digit span (measuring updating ability) and the effect of semantic interference on RT. Lastly, two positive correlations were detected between the Trail Making Task (measuring shifting ability) and the effect of semantic interference on both RT and WD. No significant correlations were detected for the healthy younger adults.

Conclusions & Implications:

Overall, the results from our study corroborate the results from several previous studies on healthy speakers who demonstrated the direct associations between executive control processes and language ability, where the semantic interference observed during single word picture-naming was found to be significantly correlated to executive control processes, specifically working memory and inhibitory control. It is evident that additional studies are needed to further explore the relationship between the healthy ageing process on spoken language production and executive control abilities, through investigating the impact of cognitive decline on lexical access and speech motor control.

4.2 Introduction

Whilst research in the past several decades revealed robust and dynamic influences of language, cognition, and speech movement on word production (Dromey & Benson, 2003; Kello, Plaut, & MacWhinney, 2000; Maner, Smith, & Grayson, 2000), evidence from recent research has supported the possible associations between linguistic, speech motor, and executive control in the area of speech production in healthy young children (Nip & Green, 2012), healthy older adults (Sadagopan & Smith, 2013), as well as impaired children and adults (Kleinow & Smith, 2000; Maner, Smith, & Grayson, 2000; Sadagopan & Smith, 2008; Walsh & Smith, 2011). Such research is vital when considering the speech motor systems of the advanced ageing population, particularly those with motor speech disorders such as aphasia, Parkinson's Disease, and Alzheimer's. The decline of language, executive control, and speech motor control in healthy older adults (Finkel, Reynolds, McArdle, & Pedersen, 2007; Luo & Craik, 2008) as well as in certain populations with speech impairments (Janvin, Psych, Larsen, Aarsland, & Hugdahl, 2006; Ravizza, McCormick, Schlerf, Justus, Ivry, & Fiez, 2005; Williams, Gray, Foltynie, Brayne, Robbins, & Barker, 2007) has been widely documented, making the interaction between language, executive control, and speech motor control particularly relevant. However, the nature of the interaction and the influence between language, specific cognitive processes, and the speech motor system on the healthy ageing population has not yet been explored in detail. As speech production is the result of the combination of the interactions between language, cognition, and speech motor systems, it is imperative that we consider all three aspects of communication in the study of word production. Thus, this present study aimed at exploring the relationship between linguistic (lexical access), speech motor performance (WD), and executive control (specifically inhibition, switching, and the updating of working memory) performance on the healthy ageing population.

As discussed in Chapter 1, this study follows the executive function theory proposed by Miyake et al. (2012) which posits that there are three main aspects of executive control: inhibition, updating of working memory, and shifting. Inhibition refers to the individual's ability to intentionally suppress dominant, automatic, and/or proponent responses while ignoring peripheral information (Stroop, 1935). Updating refers to the individual's ability to evaluate and monitor incoming information and appropriately revise the existing information and replace/delete what is no longer relevant with new, more relevant information (Miyake et al., 2000; Morris & Jones, 1990). Lastly, shifting (switching) is the individual's ability to flexibly shift attention forward and backwards between multiple tasks, processes, or mental sets. While these three executive function tasks share some common components as discussed in Chapter 1 (section 1.1.5), the Miyake et al. (2000) framework proposed that the three executive control components were clearly separable. Therefore, the Word Colour Stroop (Stroop, 1935) and the Spatial Stroop (Funes & Lupianez, & Milliken, 2007) were chosen to create a load primarily on inhibition, the Digit Span (Wechsler, 1997) and the N-back (Kirchner, 1958) on updating, and the Same Different Switching Judgment (Prior & MacWhinney, 2010) and the Trail Making Test (Tombaugh, 2004) on shifting.

4.2.1 Effect of Healthy Ageing on Executive Control Processes

The process of healthy ageing is often associated with a decline in numerous abilities and functions, including but not limited to: lexical access, speech motor control, memory, attention, and executive control (Aoki & Fukuoka, 2010; Park et al., 2002; Salthouse, 1996; Salthouse, 2009; Darbutas et al., 2013). Many studies in advanced ageing have revealed that during the healthy ageing process, older adults tend to exhibit noticeable and predictable deficits in cognitive abilities (Harada, Natelson, Love & Triebel, 2013; Salthouse, 2012). Most noticeable is the decline in executive cognitive function abilities that involve inhibition, task switching, multitasking, memory, attention, and problem solving (Lezak, Howieson, Biegler & Tranel, 2012; Salthouse, 2010).

In the past decade, there has been an increasing focus on the decline of executive cognitive control processes and the effect of those deficits on the healthy ageing process. Hasher, Zacks, and May (1999) proposed The Inhibition Deficit Hypothesis (IDH) in order to explain the cognitive declines that occur in heathy ageing adults. The IDH suggests that the age-related deficits and impairments observed in healthy older adults are manifestations of the weakened inhibitory processes in working memory that accompany advanced ageing. Specifically, the authors have assumed that decline of inhibitory control might account for the cognitive deficits associated with ageing. Older adults' failure to suppress/inhibit irrelevant information from remaining active in the working memory effectively reduces the working memory's capacity by denying access to the relevant information (Gerard, Zacks, Hasher, & Radvansky, 1991; Hasher & Zacks, 1988). For example, during the backward digit span task (which taps into working memory), the participant is asked to repeat long strings of digits backwards. The IDH assumes that healthy older adults fail to delete/inhibit the previous digits from their working memory, which consequently reduces the available "working space" for the new stimuli. A great deal of evidence supporting the IDH has been generated from interference studies that have confirmed the age-related decline in working memory and inhibitory ability, where older adults sustain access to irrelevant information that was once considered relevant, causing increased competition between the current, relevant information and the prior, irrelevant information (Hamm & Hasher, 1992; Hasher, Zacks, & May, 1999; May & Hasher, 1998).

In a recent study by Healey, Hasher, and Campbell (2013), the memory retrieval and inhibitory abilities of 141 healthy young adults (mean age 19.7) and 136 healthy older adults (mean age 67.7) was measured. The study included three tasks: in the first, participants viewed 15 words with 15 competitors below them and were asked to indicate the number of vowels in each word (i.e., Target word: Allergy, Competing word: Analogy); in the second, participants were asked to complete word fragments that resemble two words (i.e., a_l_ _ gy, target word: allergy, competitor: analogy); and finally, participants were asked to name pictures in two conditions (control and interference condition). Results from their study demonstrated the vast difference in how healthy younger and older adults resolve interference. They found that the healthy younger adults' ability to suppress competitors was significantly better than that of the older adults, as measured by reaction times. The researchers suggest that the healthy older adults' inability to sufficiently and adequately suppress competitors creates difficulties in the accurate retrieval of information for memory.

Additionally, a comparison study between healthy younger adults (age range = 20-33 years, M= 25) and healthy older adults (age range = 60-80 years, M= 67) was conducted by Fisk and Warr (1996), where subjects participated in three tasks measuring perceptual speed, working memory, and executive control. A letter comparison speed task was used as a measure of perceptual speed where participants were asked to identify if the two rows of letters displayed on a screen were similar or different. A reading span was used as a measure of working memory where participants were required to answer a question about a sentence they had read, such as "At Wimbledon it rained during June, spoiling the tennis," followed by a question with alternative choices "When did it rain? August-June-May-." Having answered the questions, the participants were asked to write down the last word of each sentence. The measurement of reading span was considered the maximum number of words successfully recalled. Lastly, a random letter generation task was implemented as measure of executive control where participants were asked to generate a set of 100 letters in a random sequence at

3 different rates: one letter every four seconds, one letter every two seconds, and one letter every second. Substantial deficits were observed in all three tasks for the healthy older adults, indicating a significant correlation between age and task performance. Additionally, a regression analysis revealed an interaction between age, perceptual speed, and working memory. These results are suggestive of the decline of executive control processes, perceptual speed, and working memory that is associated with advanced ageing. As previously discussed, the healthy ageing process is associated with declines in linguistic, speech motor, and executive control processes. Therefore, in this study we aimed to establish the possible association between ageing decline and performance in those processes.

In summary, the field of cognitive ageing in the healthy population is a comprehensive and multidisciplinary field with findings from research in the neuroscience, neuropsychology, and neuroimaging fields. Specifically, the decline in executive control processes has been the focus of numerous geriatric behavioural, neurological, and cognitive studies (see Drag & Bieliauskas, 2010; Rabbitt, 1997 for reviews). As indicated in the studies above, cognitive decline is associated with advanced ageing, with significant deficits in working memory (Badcock, 1991; Salthouse, 1994), attention (Brown & Brockmole, 2010), and inhibition (Healey, Ngo & Hasher, 2013). Other studies have also indicated the decline of speech motor and language processes in healthy older adults. However, the consequence of the decline of all three processes (lexical access, speech motor control, and executive cognitive processes) on healthy ageing individuals has yet to be measured.

4.2.2 Evidence of Interaction between Word Production and Executive Control Functions in Healthy Adults and Ageing Adults

Several previous studies on healthy speakers have demonstrated the direct associations between executive control processes and language ability, where the semantic interference observed during single word picture-naming has been found to be significantly correlated with executive control processes, specifically working memory and inhibitory control (Belke, 2008; Crowther & Martin, 2014; Shoa et al., 2015). Furthermore, results have also indicated that poor executive control contributes and/or exacerbates language deficits in healthy and impaired populations (Keil & Kaszniak, 2000).

The association between healthy ageing, executive control processes, and spoken word recognition and production was examined in a study by Taler, Aaron, Steinmetz, &

Pisoni (2010). Sixteen healthy older and twenty-one healthy younger adults were asked to hear and then repeat sentences that included three words that were either high or low in word frequencies and phonological neighborhood densities. The sentences were also spoken in the presence of a multi-talker at two-signal ratios (+10 dB and -2 dB) to act as a distraction, so that the participants could be asked to ignore (inhibit) the distraction and focus on the main sentence. Results of their study indicated that spoken word recognition and word production are significantly affected by the decline in inhibitory control in healthy older adults. As a group, reaction times were longer for sentences that included high neighbourhood densities and response durations were longer for sentences with low neighborhood densities. However, the healthy older adults were affected significantly more than the younger adults. The results clearly display the effects of healthy ageing on spoken word recognition and word production and the complex interplay between these two language processes and inhibitory control.

Bialystok, Craik, and Luk (2008) compared 24 healthy younger (mean age 20.7) and 24 older (mean age 67.2) participants on a battery of tasks assessing working memory, lexical access, verbal fluency, and executive control. The forward and backward Corsi block span and self-ordered pointing test were used to assess working memory, the Peabody Picture Vocabulary Test to assess vocabulary, the Boston naming task to assess lexical access, and the letter and category fluency tasks to assess verbal fluency. Similarly, executive control was assessed through the testing of the Simon task, word colour Stroop, and the Sustained Attention to Response tasks. Analysis of their data confirmed that due to the effective executive control processes, as depicted in smaller Stroop and Simon effects, the healthy younger adults were affected minimally by lexical competition in both the picture-naming in the Boston Naming task and the fluency tests. On the other hand, the healthy older adults were significantly affected by the decline in executive processes. They made more errors overall on all tasks (measuring lexical access, fluency, working memory and executive control), generated fewer responses in both fluency tests, and had slower reaction times on all tasks compared to the younger participants.

In another study, Crowther and Martin (2014) attempted to investigate the association between picture-naming and executive control by comparing 41 healthy younger adults (mean age: 25.6, range 18 years to 43 years) and 42 older adults (mean age: 62.9, range: 45 years to 80 years) on a semantically blocked picture-naming task and three executive function tasks (word span, verbal Stroop, and recent negatives). Word span was used to measure working memory, the Stroop and recent negatives tasks were used to measure inhibition. A correlation was performed to investigate the interaction between the executive function tasks and interference slopes for the homogenous as well as the heterogeneous conditions. Findings revealed a significant correlation between working memory (word span) and a decrease in semantic interference across the trials in both conditions of naming. Longer word spans correlated to smaller semantic interference effects. Likewise, to the extent that inhibition is related to selecting a word from semantically related competitors, better ability to inhibit a distractor, as measured by the Stroop task, was associated with the reduction of interference across cycles in the homogenous condition, where a response had to be selected from highly activated competitors. Additionally, a significant difference in the performance on both the word span and the verbal Stroop task for both age groups was observed, with the younger participants showing smaller Stroop interferences associated with smaller semantic interference. The results from this study indicate a strong association between inhibitory control and lexical access in picture-naming, with the healthy older adults exhibiting increased semantic interference associated with an increase in Stroop interference.

Additionally, Sommers and Danielson (1999) examined the correlation between semantic contexts and inhibitory abilities in 22 healthy younger adults (mean age 20) and 22 healthy older adults (mean age 75.5). The participants were asked to repeat words in conditions where there was a high neighbourhood density and low neighbourhood density, as well as perform the Garner selective attention task and the Stroop task to measure inhibitory abilities. Correlation analyses were conducted to measure the association between inhibitory ability and reaction times on the language production tasks. The results indicated a strong significant correlation between the decline in inhibitory ability and the errors and reaction times on the language production tasks (repetition and spoken word recognition) for the older adults. The authors suggested that the increase in errors and reaction times on the words that had a high neighborhood density in the healthy older adults was due to their inability to inhibit alternative words that were competing for lexical selection.

As can be seen in the previous studies, executive control and linguistic abilities are synergistic, and the correlational decline in naming ability with ageing may be multifactorial. The results of the studies discussed above provide further evidence of the involvement of the executive control processes on word production in healthy ageing. What has been given minimal attention, however, is the association between executive control and speech motor processes. Therefore, the use of an extensive battery of tests on each of the three domains for executive control in this study will provide clear and well-defined associations between executive control and both naming and speech motor processes.

4.2.3 Evidence of Interaction between Executive Control and Motor Control Processes in Healthy Young Adults and Ageing Adults

The relationship between executive control processes and motor control has been examined in numerous studies investigating motor programming through the use of simple manual tasks such as the movement of or tapping of a finger (Baldo, Shimamura, & Prinzmetal, 1998; Smiley-Oyen & Worringham, 1996), foot movement (Brass & Cramon, 2007), and hand movement while concomitantly engaging in an executive control task such as Stroop. However, studies have seldom investigated the extent to which executive control processes are interrelated to speech motor production.

Kello, Plaut, and MacWhinney (2000) investigated the relationship between inhibitory abilities and speech motor processes in 28 healthy participants. The researchers implemented a speeded Stroop task as a measure of inhibitory control while measuring error rates, reaction times, and verbal response durations during colour-naming in congruent and incongruent trials. Their results revealed that the incongruent trials instigated an increase in error rates, reaction times, and verbal response durations. Moreover, the Stroop effect, the difference between the incongruent and congruent trials, was also found to be significantly correlated to verbal response durations. The analysis of their study demonstrates the clear influence of executive control processes on speech motor control, as the durational analysis depicted the inference caused by the incongruent tasks directly causing an increase in colour-naming durations.

Likewise, in a study by Dromey and Benson (2003), the influence of cognitive, motor, and linguistic tasks on speech motor output was investigated. Twenty healthy young adults (mean age 22.7) were asked to simply repeat a sentence “Mr. Piper and Bobby would probably pick apples” or simultaneously repeat the previous sentence in one of three conditions: a motor task (while manipulating nuts and bolts), a linguistic task (generate new verbs for the end of the sentence), and a cognitive task (counting backwards by 7’s from 100 and adding that number to the end of the sentence; i.e., “Mr. Piper and Bobby would probably pick 93 apples”). Utterance duration as well as the movements of the upper lip, lower lip, and jaw were recorded while the participants partook in the tasks. The authors found that the rate of speech and lip movement consistency was significantly affected when participants repeated the sentence in the linguistic condition (generation of new verbs) and the cognitive condition (counting backwards by 7's) as compared to speech-only and the motor condition. Nevertheless, the authors also found that lip displacement and velocity were significantly reduced during the motor condition. Those findings clarify the possible impacts that linguistic and cognitive processes have on speech motor characteristics. The authors provide an explanation for their results by suggesting that both linguistic and cognitive processing take place in areas of the brain that are adjacent to areas related to speech movement sequencing, which in turn generates interference by the competition of the available resources.

In a recent study by Rietbergen, Roelofs, Ouden, and Cools (2019), the influence of executive control processes (updating, inhibiting, and shifting) on response modality (verbal vs motor) was assessed in 40 healthy participants (age ranged 18-30) using a Flanker task. The participants were shown sequences in two conditions: a congruent condition, where arrows were all pointing in one direction either left (<<<<<) or right (>>>>>), and an incongruent condition, where the targeted answer was flanked between two distractor arrows on each side (<< > <<) or (>> < >>). The stimuli were also presented in two difficulty levels: simple stimuli containing only arrows, or compound stimuli in which the authors combined arrows with a dashed line either above or below the arrows (_>_>_>_>_>). For the simple stimuli, the participants were asked to indicate the direction the arrow is pointing to by saying "right" or "left" (verbal response) or by pressing a left or right button on an answer box (motor response). For the compound stimuli, the participants were asked to indicate the direction of the arrow as "right" or "left" and the position of the line as "low" or "high" by either verbally saying the direction and the location or by sequentially pressing the required buttons on the answer box. Using the Flanker task outlined above, the researchers measured the influence of updating (by measuring the effects of length, as in the difference in reaction times between the short and long phrases), inhibition (by measuring the effects of distractors, as in the difference in reaction times between the congruent and incongruent trials) and shifting (by measuring the difference in reaction times between the switch and repeat trials) on the production of comparable verbal and motor responses. Reaction times were significantly affected in all three executive control processes in both verbal and manual responses, indicating the direct influence of executive control abilities on speech production.

Essentially, Lieberman (2015) emphasised the importance of the integration of speech motor and language processes, noting that "the neural bases of human language are intertwined with other aspects of cognition, motor control, and emotion" (p. 33). In summary, numerous studies have isolated the influence of linguistic factors (Kleinow & Smith, 2000; Maner, Smith, & Grayson, 2000; Walsh & Smith, 2011) as well as executive control abilities (Dromey & Bates, 2005; Dromey & Benson, 2003) on speech motor performance. The researchers of the studies discussed above agree on the possibility that linguistic, executive control, and speech motor factors interact in complex ways and, sequentially, have dynamic effects on the final output in speech production. Correspondingly, authors of several other studies have indicated the need for further research in the influence of linguistic and executive control processes on speech motor control to enhance our knowledge on the production of spoken word production (Maner, Smith, & Grayson, 2000; Strand, 1992; Strand & McNeil, 1996). In view of the aforementioned evidence, the present study explored whether lexical access, speech motor performance, and executive control processes interact and/or influence one another.

4.3 The Current Investigation, Research Questions, and Predictions

Given that possible interactions between executive control and both linguistic processes and speech motor processes have potential implications for the success of the assessment, treatment, and study of healthy ageing populations as well as adults with motor speech impairments, it is imperative that research focuses on the influence of all three processes on healthy ageing adults. Therefore, this current study investigated the interaction of linguistic processes, speech motor performance, and executive control on 30 healthy younger and 30 healthy older adults.

To explore how linguistic and speech motor processes in word production are influenced by inhibitory, updating, and shifting processes, this study utilised a non-cyclical semantically blocked picture-naming task to measure the effect of semantic interference on linguistic processing whilst articulatory complexity was simultaneously manipulated as a measure of speech motor control (Chapter 2). Reaction times (RT, as a measure of linguistic processing) and word durations (WD, as a measure of speech motor performance) were used for the analysis of the picture-naming task. Executive control was assessed with two individual measures for each of the three targeted sub-domains of executive control, inhibition, working memory, and task switching, based on the Miyake et al. (2000)

framework of executive control. The spatial (Bialystok et al., 2008) and word colour Stroop (Scott & Wilshire, 2010) were implemented as measures for inhibition, the n-back (Callicott, 1999) and digit span task as measures of the updating of working memory, and the trail making and the same different tasks (Prior & MacWhinney, 2010) as measures of task switching. Reaction times, error rates, Stroop ratio, and the d-prime were measures used for the executive control tasks.

Specifically, in this present study, we examined whether inhibition, updating of working memory, and switching abilities would in fact be related to the size of semantic interference effects on the RT's (linguistic processes) and WD's (speech motor processes) during naming in the blocked non-cyclic naming task. Therefore, correlation analyses were implemented to determine whether there was in fact a possible association between indicators of executive control abilities and the semantic interference effects on linguistic and speech motor processes. The research aims and predictions were the following:

1- To determine the difference between the performance of executive control measures between the healthy younger and healthy older adults.

Current and previous studies on executive control abilities have indicated that healthy adults older adults have poorer inhibitory abilities and reduced memory span (Hasher and Zacks, 1988; Hasher et al., 2007). Although no study to date has measured the shifting ability in healthy ageing adults, we predict ageing differences would be apparent on all executive control tasks.

2- To determine the relationship among the effect of semantic interference on the accuracy, RT (linguistic processes), and WD (speech motor performance) during picture naming and executive control processes (inhibition, updating, shifting) in) in healthy younger and older adults.

As empirical evidence has confirmed, ageing is significantly associated with a decline in inhibition and updating aspects of executive functioning, motor processes, and lexical access. In this study, we would assume that there would indeed be age differences in the correlation analyses, with the healthy older adults exhibiting greater effects of the semantic interference during naming in their RT and WD.

4.4 Methods

4.4.1 Participants

The same group of HYA and HOA that participated in study 1 (Chapter 2, section 2.4.1) were participants in this study as well.

4.4.2 Design, Procedure, and Apparatus

Data collection took place in a participant's home or at the speech and language therapy clinic at the University of Reading. The participants in this study were administered a battery of six executive control tasks containing specific measures of inhibiting (Word Colour and Spatial Stroop), updating (N-back tasks, Digit Span tasks), and switching (Same-different Switch Task, Trail Making Task). All but the Trail Making and the Digit Span tasks were implemented using a Toshiba Protégé through the E-Prime 2.0 software (Schneider & Zuccoloto, 2007). Responses for the tasks which utilised E-Prime tasks were measured by a Serial Response Box (Psychology Software Tools Inc.), with the exception of the N-Back task where only a single computer keyboard response was required, and the word colour Stroop where RT was measured using PRAAT. For all computer tasks, participants were given a small number of practice trials before beginning each task. Table 4.1 below provides a complete summary of all the targeted executive control tasks.

Table 4.1: *Measures of Executive Control used in the Current Study*

Executive control measures	Type of trials/conditions	Variables measured in each task	Description
		Measures of inhibition	
Word and Spatial Stroop task	Neutral, congruent and incongruent	Mean RT and percentage Stroop ratio	- A lower Stroop ratio indicates better inhibitory control.
		Measures of working memory	
N-back	1-back and 2-back	D prime (d') score	-D-prime (d') (Macmillan & Creelman, 1990) is a sensitivity measure of the participant's performance in discriminating updating trials from fill trials. -Larger d' score indicates better working memory performance.
Digit Span	Forward and backward digit span	Digit Span	-Larger digit span indicates better working memory.
		Measures of task switching	
Colour-shape task	Switch and non-switch	Mean RT and Switch cost, Percentage Switch Ratio	-Lower switch cost means smaller difference between switch trial (difficult condition) and non-switch trial (easier condition).
Trail Making Test	Switch and non-switch	Percentage Switch Ratio	-A lower Switch ratio indicates better switching ability.

Note: Word Colour Stroop (Stroop, 1935), Spatial Stroop (Funes & Lupianez, & Milliken, 2007), the Digit Span (Wechsler, 1997), N-back (Kirchner, 1958), Same Different Switching Judgment (Prior & MacWhinney, 2010), Trail Making Test (Tombaugh, 2004).

4.4.2.1 Tasks of inhibitory control. Two tasks were used in this study to tap into the inhibition aspect of execution functioning: the spatial Stroop and word colour Stroop. According to Miyake et al. (2000), the Stroop test is an ideal task for examining the inhibition aspect of executive functions. The Stroop task has been implemented in the field of experimental psychology since 1935, making it one of the oldest paradigms in the field (Stroop, 1935). In our study we incorporated two different Stroop tasks, one is the word colour Stroop (Stroop, 1935) and the other is the spatial Stroop (Funes, Lupianez, & Milliken, 2007). Both of the Stroop tasks used included three different conditions: neutral, congruent, and incongruent. In the neutral and congruent trails, there are no distractors and participants can rely on well-learned habitual processes to produce fast and accurate responses (naming colours, reading the words, and simply answering where the arrow is pointing to). In contrast, in the incongruent trials, in order for the participants to answer accurately, they are forced to use their cognitive control to inhibit the competitors and the distractors. The participants are required to suppress their automatic tendency to respond and use their inhibition skills, which in turn makes their response time longer (i.e. read the word that is written rather than say the colour it is written in). The Stroop task has been conducted in numerous studies in many different variations. In this study, a computerised version of the classic Stroop task was utilised (Mitrushina et al., 2005; Miyake et al. 2000, Salthouse et al., 2003, Scott & Wilshire 2010).

4.4.2.1.1 Spatial Stroop trails and procedures. As previously mentioned, the spatial Stroop task is used as a method of measuring the individual's inhibitory processes and ability to suppress competitors. In this task, an arrow pointing to the left or right appears randomly on a computer screen. Participants are given these instructions: "An arrow will appear on the screen. In this task you should decide what direction the arrow is pointing to. You should ignore the location of the arrow. Respond to the arrow direction using the response box as fast and as accurate as you can. There will be some practice items to begin. Please press the space bar to start." The participants were instructed to press the "←" key if the arrow they see is pointing to the left and press the "→" key if the arrow they see is pointing to the right. The subsequent arrow will only appear after a response has been made on behalf of the participant. Overall, this task included 3 different conditions: neutral, congruent, and incongruent. In each of the conditions there are 6 practice items to guarantee that the participant comprehended the task and 24 test items. After each condition, the participant is asked if a break is needed. The variables measured in this task are RTs and accuracy which were automatically measured using the computer programme E-prime.

In the neutral condition, the arrows are located in the middle of the screen and are pointing in the same direction that it is located in. In the congruent condition, the arrows are on the sides of the screen and point to the direction of their own location, for example if the arrow is on the left side of the screen the arrow is pointing to the left. Lastly, in the incongruent condition the arrows are located on the sides of the screen, pointing to the opposite direction of their location. For example, if the arrow is on the left side of the screen it is pointing to the right. See Figure 4.1 for a sample of 3 consecutive trials in the neutral, congruent, and incongruent conditions.

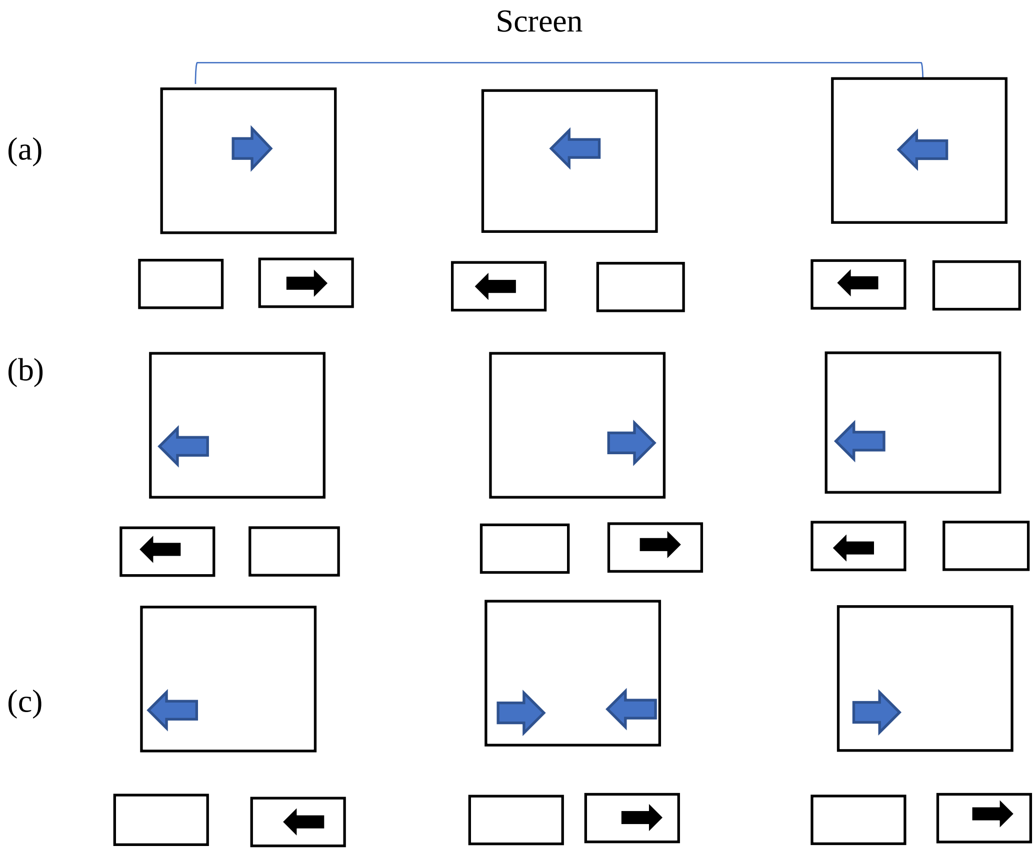


Figure 4.1 Sample of the experimental tasks in the n-back task for the (a) neutral, (b) congruent, and (c) incongruent trails.

4.4.2.1.2 Word colour Stroop trails and procedures. The word colour Stroop task utilised in this study was adapted for computer administration (Stroop, 1935). This task included three different conditions: (1) Neutral, where a coloured square (either blue, yellow, purple, red, green, or orange) was depicted on the computer screen and the participants were instructed to name the colour they could see; (2) Congruent, where the names of colours were written in black ink and the participants were asked to read the word they could see (e.g., BLUE); and (3) Incongruent, where the participants were instructed not to read the word they could see, but rather to say the colour that the word is printed in (e.g., the word "red" is printed in the colour blue). This method of measuring the inhibition aspect of executive functions has been previously used in studies on healthy adults as well as people with neurogenic disorders (Faroqi-Shah et al. 2018, Miyake et al., 2000, Salthouse et al., 2003, Scott & Wilshire, 2010). Figure 4.2 depicts the trails for all three conditions.

The procedure was the same for all three conditions: each task began with an exercise consisting of 6 practice items followed by 50 test items. In all the trails, a 'beep' would be heard simultaneously with the projection of the targeted stimulus and the participants' responses were then measured for RT analysis. Participants were instructed to answer as accurately and as quickly as possible. After each of the three tasks mentioned above the participant was given a short break. The variables measured in this task were accuracy, RT, and the Stroop ratio. The responses were tape recorded and the RTs were later analysed using PRAAT.

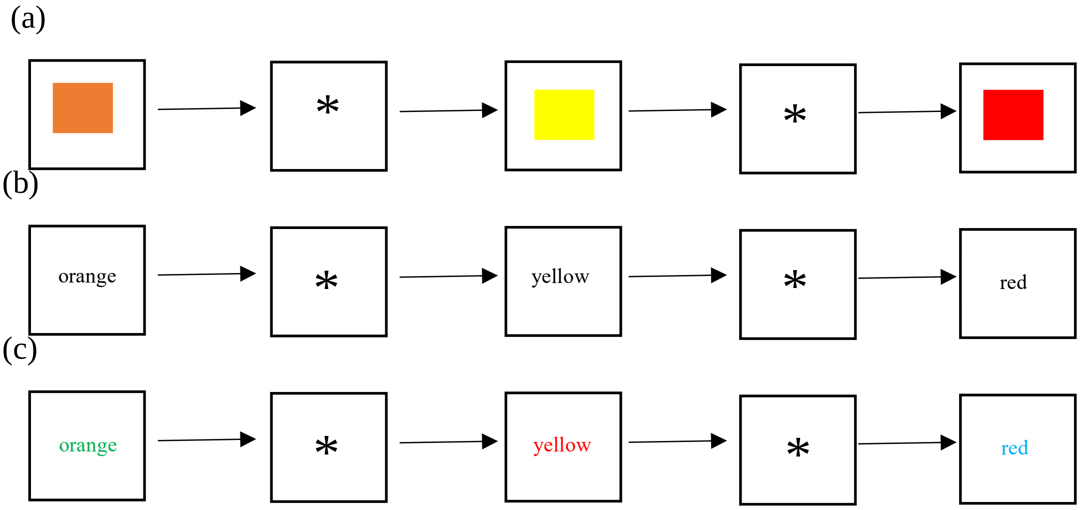


Figure 4.2 Sample of the experimental tasks in the word colour Stroop task for the (a) neutral, (b) congruent, and (c) incongruent trails.

4.4.2.1.3 Variables measured: Reaction time (RT). RT was measured for each condition separately (neutral, congruent, and incongruent) using PRAAT. The mean RT for participants was calculated by averaging the reaction time over all trials in each condition.

4.4.2.1.4 Variables measures: Stroop ratio. Previous studies measured Stroop effect as the only measure of Stroop interference. However, relying solely on the Stroop effect (difference between the mean RT of the neutral and incongruent conditions) can yield similar results in participants even if the interference effects differ (Andrew & Balota, 2015; Bialystok et al., 2008; Scott & Wilshire, 2010). To elaborate, if participant A demonstrates a mean RT of 900 ms in the incongruent condition and a mean RT of 300 in the neutral, the Stroop effect would be 600 ms. Moreover, if participant B demonstrates a mean RT of 1200 in the incongruent condition and a mean RT of 600 ms in the neutral condition then that would also yield a Stroop effect of 600 ms. Although both participants demonstrated the same Stroop effects, this effect unfortunately fails to demonstrate the overall difference between participants A and B, where participant B is significantly slower in both the neutral and incongruent conditions. This overall slowness is a crucial factor in assessing Stroop interference - therefore, the percentage Stroop ratio was applied in this study to account for overall speed differences in responses.

The Stroop ratio is calculated by dividing the difference of the mean of the incongruent trial from the mean of the neutral trial by the mean of neutral and incongruent trials divided by two, and then multiplied by 100. A lower Stroop ratio indicates a better inhibitory control where a higher Stroop ratio indicates difficulty in inhibition.

$$\text{Stroop Ratio} = \left(\frac{\text{Incongruent Trial mean RT} - \text{Neutral Trial mean RT}}{\frac{\text{Neutral Trial mean} + \text{Incongruent Trial mean}}{2}} \right) \times 100$$

4.4.2.2 Tasks of working memory (updating). Two tasks are used in this study to tap into the updating aspect of execution functioning: the n-back and the digit span. According to the definition of executive functioning proposed by Miyake et al. (2000), the digit span and n-back tasks both cover the executive function of updating and monitoring the working memory, as this executive function is closely linked to the conception of working memory.

4.4.2.2.1 N-back. The n-back task requires the involvement of diverse executive processes, such as working memory, regulating attention, updating, monitoring of ongoing performance, and the inhibition of interfering items (Conway, Kane, & Engle, 2003; Jaeggi et al., 2009; Kane et al., 2007). Due to the constant need for the participant to update representations of the serially presented stimuli in the working memory while choosing the relevant stimuli and mentally deleting the representation of the irrelevant stimuli, the n-back task incorporates numerous aspects of executive functioning. The n-back task used in this study has been incorporated in previous neuropsychological studies for the purpose of testing executive functions (Jaeggi et al., 2010, Minear et al., 2016; Salminen et al., 2012).

4.4.2.2.2 N-back trails and procedures. In this task, the participants were presented with a one-by-one sequence of stimuli. The stimuli consisted of a single square that appeared randomly in eight different possible locations of the computer screen. The participants were instructed to press the response key when the current stimulus matched the one from *n* steps earlier in the sequence (the *n* is either 1 or 2 trials earlier depending on the task). If the location did not match the location n-back, the participants were instructed to make no response. The participants were given the following instructions: "one at a time you will see a square appear on the screen. You need to monitor the location and press the response square when the square you see is in the same location as the square that appeared one trial before, or 1-back. Try to respond quickly as another square will appear afterwards." This task included 4 test blocks with 29 cycles in each block, each stimulus appearing on the screen for a total of 500 ms. Consequently, after each test block, the participants were asked if a short break was required and to press the response key when they were ready for the next block. A sample of 5 consecutive trials for both the 1-back and 2-back can be seen in Figure 4.3.

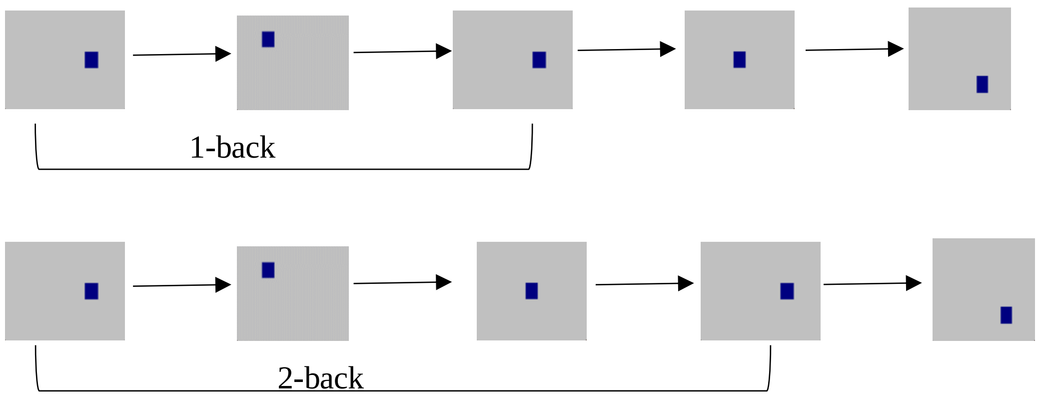


Figure 4.3 Sample of the experimental tasks in the n-back task for the neutral, congruent, and incongruent trails.

4.4.2.2.3 Variables measured: D-prime (d'). Responses in this task were categorized as hits (signal is present), misses (signal is present, but participant incorrectly indicated that there is no signal), false alarm (participant incorrectly responds with a hit) and correct ignore (where the participant correctly ignores a no signal) (Haatveit et al., 2010). In our experiment, 'signal' refers to the 'updating trials' and 'no signal' refers to 'filler trials'. The measurement of D-prime (*d'*) (Macmillan & Creelman, 1990) was implemented as a sensitivity measure of the participant's performance in discriminating the updating trials from filler trials. The formula for the calculation of *d'* is:

$$d' = \text{Hit} - \text{FA}$$

Where 'Hit' refers to the proportion of hits when a signal is present (hits/ (hits + misses)), also known as the hit rate, 'FA' represents the proportion of false alarms when a signal is absent (false alarms/ (false alarms + correct ignore)), the false-alarm rate. A higher *d'* is indicative of better updating abilities.

4.4.2.2.4 Digit span. The Digit Span task (Wechsler, 1997) is the oldest and most common tool used for measuring the span of immediate verbal recall and short-term verbal memory (Lezak et al., 2012). The use of the forward and backward digit span has been used widely in clinical and non-clinical samples and has proved to be a good indicator of the impairment of executive functions (Curtiss et al., 2001; Dobbs et al., 2001, Groeger et al., 1999; Härting et al., 2000; Jaeggi et al., 2008; Richardson, 2007; Woods et al., 2011). This task has been helpful in measuring working memory performance (Wilde, Strauss & Tulsky, 2004), specifically the backward digit span.

4.4.2.2.5 Digit span trails and procedures. This task consisted of two conditions: the forward digit span and the backward digit span. The task began with the instructions for the forward digit span, which read as follows: “I am going to say some numbers. Listen carefully, and when I am through say them right after me.” The experimenter then dictated a sequence of digits at a consistent speech rate and the participants were asked to immediately repeat the sequence correctly, with each subsequent trial having an increasingly longer sequence. The sequence of the numerical digits started at three digits and went up to eight digits. For each sequence level, two trials were given with different sequences of digits. For example, when the task began, the first trial for the three-digit sequence was 3-8-2 and the second trial was 9-1-7. The experimenter moved on to the next sequence of digits, if the participant repeated at least one trial accurately. If the participant failed both trials of a particular digit sequence, the task was discontinued, and the experimenter moved on to the backward digit span task.

The backward digit span began with the following instructions: “I am going to say some more numbers, but this time when I stop, I want you to say them backwards. For example, if I say 4-2-8, what are you going to say?” The experimenter then paused for the participant to respond. If the participant responded correctly, the task would then begin. If the participant answered incorrectly, the experimenter provided the correct answer and provided another example as well. Subsequently, the main backward digit span would commence. In this task, the experimenter dictated the digits and instructed the participant to accurately recall the digits in a reverse order. For example, the first trial for the three-digit sequence was 6-3-8 and the correct targeted response was 8-3-6. The experimenter moved on to the next digit sequence, if the participant was able to correctly recall one trial in reverse order.

4.4.2.2.6 Variables measured: digit span. The variable that was examined in this task was the digit span, which is defined as the length of the longest number of sequential digits that can be accurately remembered, in this case eight.

4.4.2.3 Tasks of mental set shifting. Two tasks are used in this study to tap into the shifting aspect of execution functioning: the trail making task and the same-different task switching (Jersild, 1927). According to the definition of executive function by Miyake et al. (2000), the trail making task (Army Individual Test Battery, 1944) and the same-different task switching task (Prior & MacWhinney, 2010) both cover the shifting aspect of executive function.

4.4.2.3.1 Same-different task switching. The colour-shape task measures switching ability, where the participants switch between shape decision and colour decision (Prior & MacWhinney, 2010). For the current study, we adapted Prior and MacWhinney's (2010) colour-shape switch task. The target stimulus was a set of bivalent stimuli, consisting of circles and triangles in two colour combinations - red and green. Participants had to judge the shape or colour of the stimuli based on the relevant cue. Colour cue was indicated by the colour gradient and shape cue by a row of small shapes in black. When the colour cue was presented, the participant was expected to judge the colour of the target stimulus (red or green) and when the shape cue was presented, the participant responded to the shape of the target stimulus (circle or triangle).

4.4.2.3.2 Same-different task switching trails and procedures. The same-different switching task consisted of three different conditions: colour, shape, and mixed. All conditions in this task included 1 trial block with 6 practice items and 40 test trials. The practice items were to ensure that the participants understood the instructions of the task. The experimenter ensured that the participants were comfortable with the position of the computer screen and the response box. Reaction times and accuracy were automatically recorded by the computerised program, E-prime, through the use of an SR- response box. In this task, the rate of the display of the stimuli is dependent on the response of the participant (i.e., the next stimulus is only displayed once the participant gives a response).

The task began with the colour condition. The instructions were as follows: "You will see two tiles. You should decide if they are the same or different colour(s). If one tile is green and the other is also green, press yes. If one tile is blue and the other one is red, press no. Try to respond as quickly and as accurately as possible.” The participants then viewed pictures of two titles on the computer screen and were asked to press the correct answer using the response box. The same instructions were provided for the shape task, where the participants were instructed to use the response box to press ‘yes’ if the two tiles were the same shape while disregarding the colour and ‘no’ if they were different. Finally, in the mixed condition, the participants were instructed with the following: “You will see two patterned tiles. This time you will need to either perform the colour task or the pattern task. If you see the colour wheel cue, perform the colour task (are they the same colour?). If you see the pattern cue, perform the pattern task (are they the same pattern?). Try to respond as accurately as possible.” The participants were asked to answer as quickly and as accurately as possible using the response box. During this condition there were 8 practice trials and 2 test blocks with 40 test items in each. After each test block the participants were able to take a short break. A sample of 3 consecutive trials in all of the conditions can be seen in Figure 4.4. The variables examined on this task were RT and accuracy.

Figure 4.4 Sample of the experimental tasks in the same-different decision task for (a) colour, (b) shape, and (c) mixed trails. - pattern cue, - colour cue.

4.4.2.3.3 Variables measured: Mean reaction time (RT). Reaction time was measured for both the switch and non-switch trials. The mean reaction time for participants was calculated by averaging the reaction time over all trials in each condition (switch and non-switch).

4.4.2.3.4 Variables measures: Percentage switch ratio. Similar to the Stroop task, previous studies investigating switching ability relied on the measurements of switch costs. Switch costs are calculated by measuring the mean RT difference between the switch task, where participants switch between one task and another simultaneously, and the non-switch task (no switching being conducted). However, similar to the Stroop task, measuring the difference between the mean RT is not a reliable measurement of switching ability. Therefore, percentage switch ratio was calculated where lower switch costs indicated faster switching ability and a smaller difference between switch trial (difficult condition) and non-switch trial (easier condition) (Kray & Lindenberger, 2000; Kray et al., 2008; Prior & MacWhinney, 2010).

$$\text{Switch Ratio} = \left[\frac{\text{Switch trial mean RT} - \text{Non-switch trial mean RT}}{\frac{\text{Switch trial mean} + \text{Non-switch trial mean}}{2}} \right] \times 100$$

4.4.2.3.5 Trail Making Test. The Trail Making Test is a neuropsychological test that "provides information on visual search, scanning, speed of processing, mental flexibility, and executive functions" (Tombaugh, 2004). This test has been utilised in most of the neuropsychological test batteries (Halstead-Reitan Battery, Neuropsychological Test Battery 65, CERAD plus) and neurological research studies (Fillenbaum et al., 2008; Tombaugh, 2004; Lezak et al., 2012; Mitrushina et al., 2005).

4.4.2.3.6 Trail Making Test trail and procedure. The Trail Making Test consisted of four parts, task A and task B being the actual main tasks and two prior tasks that served as sample exercises. All of the tasks were performed using a paper and pencil. During the main tasks, a stopwatch was used to measure the time the participant needed to complete each task.

The task started with sheet one, the exercise sample for task A, where participants were instructed to connect numbers from number 1 to number 8 in ascending order at their own pace. Sheet two was the actual task A, where the participants were instructed to connect the numbers from number 1 to number 25 in ascending order as fast and as accurately as possible without lifting the pencil from the paper. Sheet three was the exercise sample of task B, where the participant was instructed to draw lines to connect the numbers and letters alternately and in ascending order at their own pace. The numbers in the exercise were 1 through 4 and the letters were A to D. Lastly, sheet four was the actual task B, where the participant was asked to, as quickly and as accurately as possible and without lifting the pencil from the paper, connect the numbers and letters alternately in ascending order (e.g., 1-A-2-B-3-C). The numbers provided were 1 to 13 and the letters provided were A to K.

During testing, if participants made an error, the experimenter provided feedback immediately concerning their errors and the participant was asked to self-correct. The errors that the participants produced do not affect a “total” score as we are not looking at accuracy. Rather, the correction of these errors is included in the completion time for the task which is what the study is investigating. If a single task is not completed within five minutes, the task is discontinued. All the participants in this study completed both tasks in under five minutes.

4.4.2.3.7 Variables measured: Completion time and switch ratio. The time taken for the participant to complete the trials A and B were used to calculate the switch ratio with trail A being the non-switch trial and trail B as the switch trial.

4.4.3 Multiple Measures on the Executive Control Domains

As discussed previously, healthy older adults as well as neurologically impaired individuals exhibit a range of deficits on language and executive control processes (Aoki & Fukuoka, 2010; Park et al., 2002; Mayer & Murray, 2012; Salthouse, 1996; Salthouse, 2009; Seniow et al., 2009; Skurvydas & Krisciunas, 2013). These deficits instigate great difficulty in the administration and completion of executive control tasks as they require executive control as well as receptive and expressive language abilities to complete (Jefferies & Lambon Ralph, 2006). Therefore, it is vital to determine if the poor performance on the executive control tasks is from reduced executive control abilities, reduced language abilities, or both – however, the removal of language demands from the executive control tasks has proven to be challenging (Mayer & Murray, 2012).

To overcome this limitation, studies have attempted to use multiple tasks to measure the domains of executive control (Mayer & Murray, 2012; Seniow et al., 2009). While poor performance on one task alone could possibly indicate that any reduction observed in executive control performance is secondary to language impairment, impaired performance on both task versions would indicate poor executive control abilities and would not be restricted to the language domain (Kuzmina & Weekes, 2017; Murray, 2017). In this thesis, we examined the participants' performance on two different tasks in each of the three targeted executive control domains.

4.5 Outlier and Statistical Analysis

4.5.1 Outlier Analysis

Outlier analysis consisted of two steps. The first step was the removal of outliers at the task level for each participant on the executive control tasks that had multiple trials (all executive control tasks except trail making and the digit span). Outliers were indicated as any trials greater than 2.5 SD below or above the mean per participant, per task. The second step was the removal of the outliers at a group level. Boxplots were utilised to identify possible outliers on all executive function tasks. Simple outliers were indicated as any participant that performed one and a half times more than the length from either end of the box (interquartile range) and extreme outliers as three or more times the length from either end of the box. Statistical analyses were conducted both with and without the simple outliers, which ultimately produced similar statistical decisions. It was then decided that the simple outliers would not be considered influential in our correlational analysis. Therefore, for the purpose of our study it was concluded that the removal of only the extreme outliers was necessary. Table 4.2 below provides clarification as to the number of simple and extreme outliers detected in each of the executive function task. The box plots for all executive function tasks can be found in the Appendix 4.1.

Table 4.2: *Number of Simple and Extreme Outliers for the Healthy Younger and Healthy Older Adults on the Executive Function Tasks*

Executive function task	Healthy younger adults		Healthy older adults	
	Simple outlier	Extreme outlier	Simple outlier	Extreme outlier
Word colour Stroop ratio	3	1	2	0
Spatial Stroop ratio	1	0	1	0
Backward digit span	6	0	0	0
One back	2	0	1	0
Two back	0	0	0	0
Same different switch ratio	4	0	1	0
Trail Making switch ratio	3	0	1	0

4.5.2 Statistical Analysis

As the entire data set was not distributed normally in this experiment, the Mann Whitney U-test was used to measure group differences on the executive control tasks. Spearman's correlation analyses were performed separately for each group (HYA and HOA) to examine the relationship between the executive control measures (Spatial/word colour Stroop, n-back, digit span, trail making, same-different switching) and the blocked non-cyclical naming measures (effect of semantic interference on accuracy, RT, and WD).

4.6 Results

The mean and standard deviation values for the executive control tasks for both the HYA and HOA are presented in Table 4.3. The findings from the correlation analyses between the executive control measures for each are presented in Table 4.3. Findings for Group differences are presented first, followed by the findings for the executive control measures in both groups.

4.6.1 Group Differences: Executive Control Measures

As can be seen in Table 4.3 below, the two groups (HYA and HOA) differed significantly on all executive control tasks except the one-back. Although the HOA indicated smaller d-prime measures, the difference was not significant. To summarise, the HYA demonstrated smaller percentage Stroop ratios (%) on both the word colour Stroop and the spatial Stroop, which is indicative of better inhibitory control. Healthy younger adults also showed smaller switch costs, suggestive of superior shifting ability on both the trail making task and the same-different switching task. Lastly, there was no significant difference between the healthy younger and healthy older adults on the one-back task measuring updating ability.

Table 4.3: *Means, Standard Deviations (SD) for Reaction Time analysis, D-prime, and Accuracy for the HYA and HOA participants*

Executive Function Measures	Healthy younger adults		Healthy older adults		Statistical results
	M	*SD*	*M*	*SD*	
Inhibitory measures					
Word-colour Stroop					
Percentage Stroop Ratio (%)	24.33	9.07	32.13	19.36	**U = 250.00, *p*< .003**
Stroop neutral (RT)	494.78	80.85	616.30	127.73	**U = 185.00, *p* < .000**
Stroop Incongruent (RT)	640.16	128.11	855.39	205.54	**U = 146.00, *p*< .000**
Spatial Stroop					
Percentage Stroop Ratio (%)	18.14	7.53	61.61	28.11	**U= 275.00, *p*< .010**
Stroop neutral (RT)	381.98	56.26	551.67	130.15	**U= 77.00, *p*< .000**
Stroop Incongruent (RT)	427.78	127.17	666.77	226.53	**U= 125.00, *p*< .000**
Updating measures					
Digit Span					
Forward digit span	6.32	1.43	3.56	1.25	**U= 63.00, *p*< .000**
Backward digit span	4.59	1.47	2.59	.89	**U = 102.00, *p*< .000**
N-back					
1-back (d-prime value)	3.62	.72	3.42	1.10	U = 431.50, *p*=.754
2-back (d-prime value)	2.91	.71	2.49	.84	**U= 309.00, *p*< .031**
Task switching measures					
Same-Different					
Percentage switch ratio (%)	27.36	39.97	74.11	20.88	**U=-184.21, *p*< .000**
Same different colour (RT)	543.54	100.16	768.61	215.01	**U= 133.00, *p*< .000**
Same different final (RT)	1013.00	268.23	1735.72	883.73	**U = 104.00, *p*< .000**
Same different switch cost (RT)	469.445	212.62	967.11	717.30	**U = 162.00, *p*< .001**
Trail Making Test					
Percentage switch ratio (%)	75.99	31.34	58.70	26.24	**U=-238.10, *p*< .000**
Trail making A (time)	16.97	7.40	27.53	10.82	**U=-128.00, *p*< .000**
Trail making B (time)	40.20	23.53	53.97	26.39	**U = 213.50, *p*< .000**
Trail making switch cost (time)	23.23	18.63	26.43	20.39	**U= 385.50, *p*< .021**

Note. U= Mann Whitney

Accuracy and response times were obtained in all the executive function tasks except for the N-back, digit spans, and trail making tasks. Reaction time analysis was conducted after excluding the incorrect responses and outliers. Consistent with prior studies, the percentage Stroop ratio was computed by dividing the difference of the mean of the incongruent trial from the mean of the neutral trial by the mean of neutral and incongruent trials divided by two, and then multiplied by 100. The highest possible score on the word colour Stroop was 50 points for each of the three conditions. Scores for the HYA in the neutral condition were 100% for 29 of the participants, whereas in the incongruent condition the scores ranged from 48 to 50. As for the HOA, the participants answered 100% accurately in the neutral condition and they ranged between 47 and 50 in the incongruent condition. The mean for the Stroop ratio for the HYA was 24.32 and 32.13 for the HOA. On the other hand, in the spatial Stroop task, the Stroop ratio was significantly larger for the HOA with a mean of 17.82 as compared to the HYA who had a mean of 7.32. As mentioned previously, smaller Stroop ratio indicates greater inhibitory ability.

The highest score on the digit span was 24 points total with 12 points in both the forward and the backward digit spans. The range of scores for the HYA was 11 to 24 and 8 to 23 for the HOA. All of the 60 participants were capable of memorising a minimum of a 4-digit sequence in both the forward and the backward digit spans.

On the N-back task, the 2-back was of primary interest as it is suggestive of the participant's ability to update the information being presented under pressure. In the 2-back task the HYA had an average d-prime score of 2.91 whereas the HOA was 2.49. As mentioned previously, a higher d-prime indicates that HYA were able to perform better in the task than the HOA.

On the same-different switching task, the accuracy of the final task and the percentage switch ratio were measures of the participants' shifting ability. The HYA adults had a higher average of accuracy (75.5%) as compared to the HOA (74.8%). The mean percentage switch ratio for the HYA was 27.37 and 74.11 for the HOA. As mentioned above, lower switch ratios indicate faster switching ability.

Accuracy was not of interest on the Trail Making Test - the errors affected the participants' score only by increasing the time it took the participant to complete the trail. The average time it took the HYA to complete the Trail Making Test part A was 16.97 seconds and part B was 40.20 seconds, while part A took the HOA an average of 27.53 seconds and part B took 53.96 seconds. None of the HYA or HOA participants scored above the cut-off, which was the maximum time of 5 minutes to complete each of the trails. The percentage switch ratio was vital in measuring the participants' switching ability. The mean percentage switch ratio in the trail making task for the HYA was 75.99 and 58.69 for the HOA where lower switch ratios were indicative of faster switching ability.

The means, standard deviations, and D-prime values for all the participants (HYA and HOA) are presented in Table 4.3 above. Figure 4.5 depicts the means for both the HYA and HOA on the tasks measuring executive control in the three targeted domains (inhibition, updating, and switching).

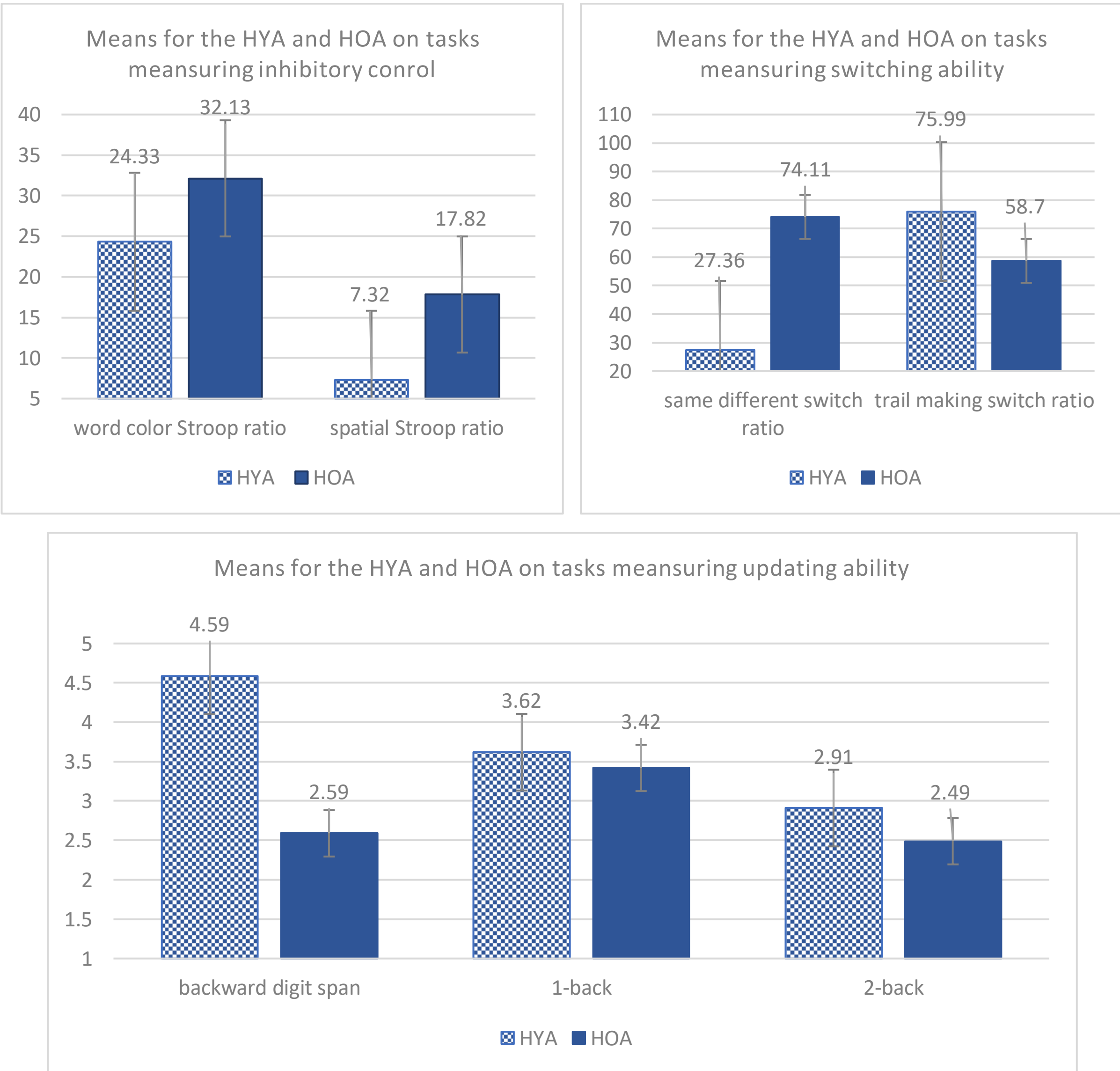


Figure 4.5 Means for the HYA and the HOA on tasks in the three targeted executive control domains.

4.6.2 Relationship between the Executive Control Measures and Semantic Interference

Normality tests were conducted and indicated that all executive function tasks were not normally distributed, therefore non-parametric Spearmans correlations were performed. The non-parametric correlations were computed to assess the relationship between the executive functions and the difference between the means of the homogenous and heterogeneous words (i.e., semantic interference) for reaction time, word duration, as well as naming accuracy in the picture-naming task. Findings from the correlation analyses between the executive control measures and the semantic interference for each of the groups, HYA and HOA, are presented in Table 4.4 below.

For the purpose of this study and the benefit of the reader we have provided a comprehensive profile in regard to the results for both the HYA and HOA on all the measures in the executive control tasks. However, the discussion will consist strictly of the variables of interest which include:

1- Word colour percentage Stroop ratio and Spatial percentage Stroop ratio as measures of inhibitory ability.
2- Backward digit span, 1-back, and 2-back as measures of updating ability.
3- Same different switch ratio and trail making switch ratio as measures of switching ability.

Table 4.4: *Statistical Results of the Correlation Analyses for the Executive Function Tasks on the Accuracy and the Semantic Interference on Reaction times and Word Durations from the Picture-naming Task for the HYA and the HOA*

Executive Function Measures	Healthy younger Adults			Healthy older adults		
	Accuracy	Reaction time	Word duration	Accuracy	Reaction time	Word duration
			Inhibitory measures			
Word-colour Stroop						
Percentage Stroop Ratio (%)	*rs* = -.105, *p*= .588	*rs* =.030, *p*= .880	*rs* =.064, *p*= .671	*rs* = 0.19, *p*= .922	*rs* = .400, *p*< .028	*rs* =.379, *p*< .039
Stroop neutral (RT)	*rs* = -.169, *p*=.371	*rs* = -.128, *p*=.500	*rs* =-.160, *p*= .371	*rs* = -.193, *p*=.308	*rs* = -.188, *p*= .321	*rs* = -.146, *p*= .441
Stroop Incongruent (RT)	*rs* = .543, *p*= .341	*rs* =.033, *p*= .861	*rs* = -.077, *p*= .687	*rs* =-.352, *p*=.066	*rs* =.458, *p*<.011	*rs* = -.324, *p*=.081
Spatial Stroop						
Percentage Stroop Ratio (%)	*rs* = -.004, *p*= .984	*rs* = -.090, *p*= .637	*rs* =-.083, *p*= .662	*rs* = -.098, *p*= .605	*rs* = .364, *p*< .011	*rs* = 342, *p*= .065
Stroop neutral (RT)	*rs* = -.317, *p*= .087	*rs* = -.207, *p*=.272	*rs* = -.308, *p*= .098	*rs* = .073, *p*= .702	*rs* = -.301, *p*= .113	*rs* =.270, *p*= .157
Stroop Incongruent (RT)	*rs* = .072, *p*= .705	*rs* = -.152, *p*= .424	*rs* = -.113, *p*= .552	*rs* = -.084, *p*= .664	*rs* = -.237, *p*= .215	*rs* = -.162, *p*= .402
			Updating measures			
Digit Span						
Forward digit span	*rs* = -.188, *p*= .319	*rs* =.177, *p*= .348	*rs* =.291, *p*= .118	*rs* = -.296, *p*= .112	*rs* =.194, *p*= .303	*rs* =.080, *p*= .675
Backward digit span	*rs* = -.009, *p* =.962	*rs* =.117, *p*= .539	*rs* =.219, *p*= .245	*rs* = -.179, *p*= .344	*rs* = -.414, *p*< .023	*rs* =.322, *p*= .083
N-back						
1-back (d-prime value)	ρ= -.174, *p*= .366	ρ= .128, *p*= .507	ρ= .139, *p*= .473	ρ= .063, *p*= .741	*rs* =.064, *p*= .738	*rs* =.174, *p*= .357
2-back (d-prime value)	*rs* =.036, *p*= .849	*rs* =.186, *p*=.325	*rs* = .177, *p*=.350	*rs* =.250, *p*= .184	*rs* =.030, *p*= .873	*rs* = .081, *p*= .672

Executive Function Measures	Healthy younger Adults			Healthy older adults		
	Accuracy	Reaction times	Word duration	Accuracy	Reaction times	Word duration
			Task switching measures			
Same-Different						
Percentage switch cost (%)	*rs* =-.045, *p*= .812	*rs* = -.122, *p*= .522	*rs* = -.185, *p*=.328	*rs* = .011, *p*= .954	*rs* = -.003, *p*= .989	*rs* = -.015, *p*= .940
Same different colour (RT)	*rs* =.016, *p*= .934	*rs* = -.034, *p*= .859	*rs* = -.123, *p*=.519	*rs* = -.277, *p*= .138	*rs* = -.138, *p*= .464	*rs* = -.060, *p*= .752
Same different final (RT)	*rs* = -.013, *p*= .946	*rs* = -.057, *p*= .764	*rs* = -.052, *p*= .786	*rs* = - .349, *p*= .063	*rs* = -.269, *p*= .159	*rs* = -.130, *p*= .503
Same different switch cost (RT)	*rs* = -.036, *p*= .848	*rs* = -.044, *p*= .815	*rs* = -.083, *p*= .662	*rs* = -.330, *p*= .081	*rs* = -.256, *p*= .179	*rs* = -.104, *p*= .593
Trail making Test						
Percentage switch cost (%)	*rs* =-.184, *p*= .329	*rs* = -.023, *p*= .906	*rs* = .057, *p*=.764	*rs* =-.147, *p*= .456	*rs* = .656, *p*<.000	*rs* = .589, *p* <.001
Trail making A (Time)	*rs* =.109, *p*= .567	*rs* = -.045, *p*= .813	*rs* = -.176, *p*= .352	*rs* =.000, *p*= .998	*rs* = -.114, *p*= .549	*rs* = -.085, *p*= .655
Trail making B (Time)	*rs* = -.267, *p*= .153	*rs* =.379, *p*<.039	*rs* = -.180, *p*= .360	*rs* = -.084, *p*= .658	*rs* = -.158, *p*=.403	*rs* =.058, *p*= .764
Trail making switch cost (Time)	*rs* =-.041, *p*= .838	*rs* =.231, *p*= .619	*rs* = .004, *p*= .985	*rs* = -.084, *p*= .672	*rs* = -.188, *p*= .338	*rs* =.034, *p*= .860

Note. rs= Spearman's Correlation.

As per the correlation analysis previewed in Table 4.4, the significant findings are as follows: the healthy younger adults displayed only one single significant positive correlation on a variable that was not of our interest for the purpose of this study (*rs* = .370, $p < .039$) between the effect of semantic interference on word duration time measures and the performance time on the Trail making task B.

In contrast, the healthy older adults exhibited numerous significant correlations. A positive correlational relationship between the semantic interference in reaction time and the percentage Stroop ratio on the word colour Stroop was found with a *rs* value of .400 and a significance of $p < .028$. The HOA participants who exhibited higher Stroop ratios on the word colour Stroop were associated with an increase of semantic interference in the reaction times. This means that the participants with a greater Stroop ratio - indicating low inhibitory control - demonstrated an increase of semantic interference in reaction times with significantly longer RT in the homogenous conditions where inhibition of the activated competing stimuli is required as compared to the heterogeneous conditions. A Scatterplot depicting this relationship can be seen in Figure 4.6 below.

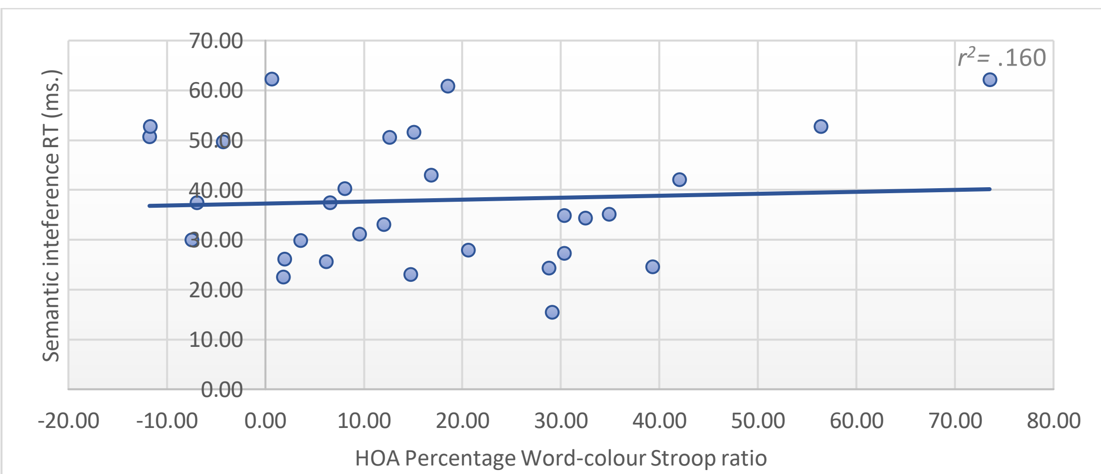


Figure 4.6 Correlation plots for the significant correlation between semantic interference on reaction times and percentage Stroop ratio on the word colour Stroop task for the healthy older adults.

Additionally, a positive correlational significance between semantic interference in word durations and the percentage Stroop ratio on the word colour Stroop was found with a *rs* value of .379 and a significance of $p < .039$. As indicated above, the HOA participants with higher percentage Stroop ratios on the word colour Stroop task were associated with an increase of semantic interference effect on word duration measures. This means that the participants with a greater Stroop ratio - indicating low inhibitory control - demonstrated an increase of semantic interference on word durations. That is, the individuals who demonstrated weak inhibitory control on the executive control measure of inhibition correspondingly demonstrated longer WD in the homogenous conditions where inhibitory control is essential in the resolution of the activated competing stimuli. A Scatterplot depicting this relationship can be seen in Figure 4.7 below.

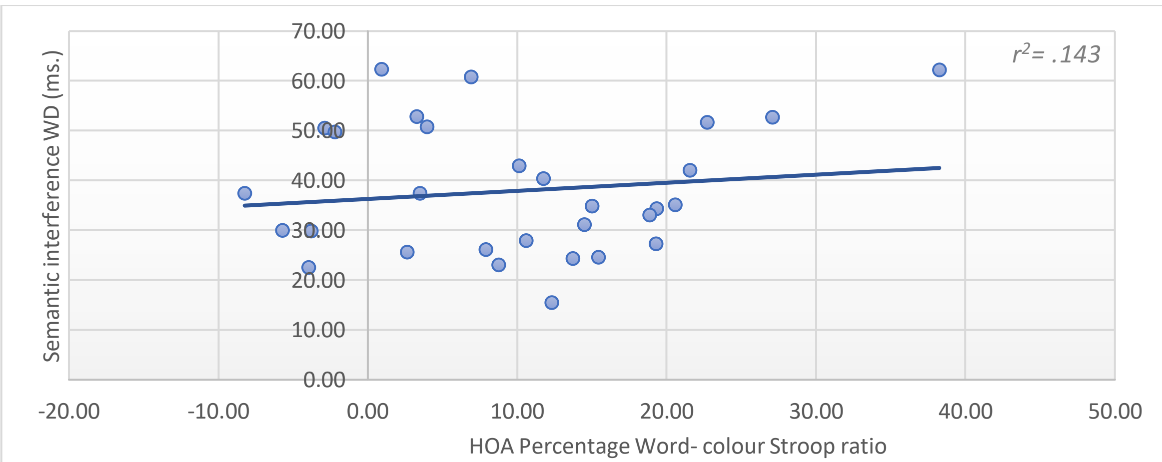


Figure 4.7 Correlation plots for the significant correlation between semantic interference on word durations and percentage Stroop ratio on the word colour Stroop task for the healthy older adults.

Similarly, a positive correlational relationship (*rs* = .364, *p*< .011) between the semantic interference on reaction times and the percentage Stroop ratio on the spatial Stroop task for the healthy older adults was found. Paralleling the results on the word colour Stroop task above, the individuals who demonstrated weak inhibitory control on the executive control measure of inhibition correspondingly demonstrated longer RT in the homogenous conditions. The correlational relationship can be seen in Figure 4.8 below.

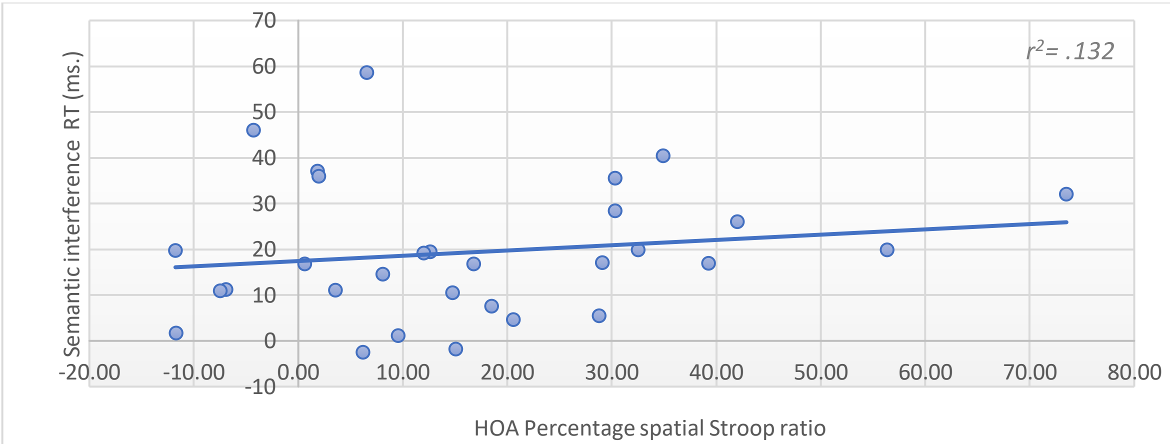


Figure 4.8 Correlation plots for the significant correlation between semantic interference on reaction times and the percentage Stroop ratio on the spatial Stroop task for the healthy older adults.

This finding suggests that the HOA participants who display larger Stroop ratios (increased interference) on the word colour Stroop and the spatial Stroop tasks simultaneously experienced an increase in semantic interference as manifested by longer reaction times and word durations in the homogenous conditions in the naming task where inhibition is essential in the resolution of the increased activation of competing stimuli.

Additionally, a significant correlation between the backward digit span and semantic interference in word durations was found for the healthy older adults with a *rs* value of -.414 and a significance of $p < .023$. This negative correlation was evident as participants who exhibited larger digit spans (greater updating of working memory ability) displayed smaller semantic interference in reaction times during picture-naming. That is, participants who demonstrated longer digit spans correspondingly demonstrated shorter RT in the homogenous conditions during picture-naming. The correlational relationship can be seen in Figure 4.9 below.

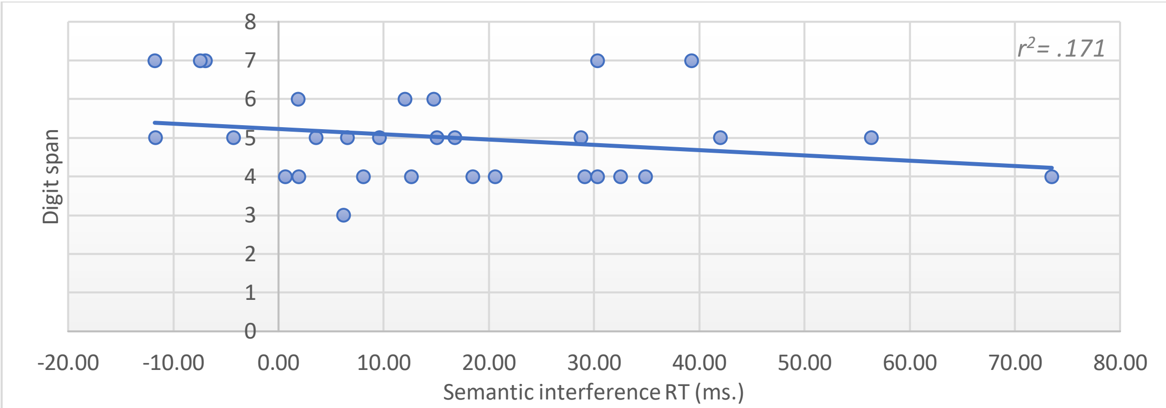
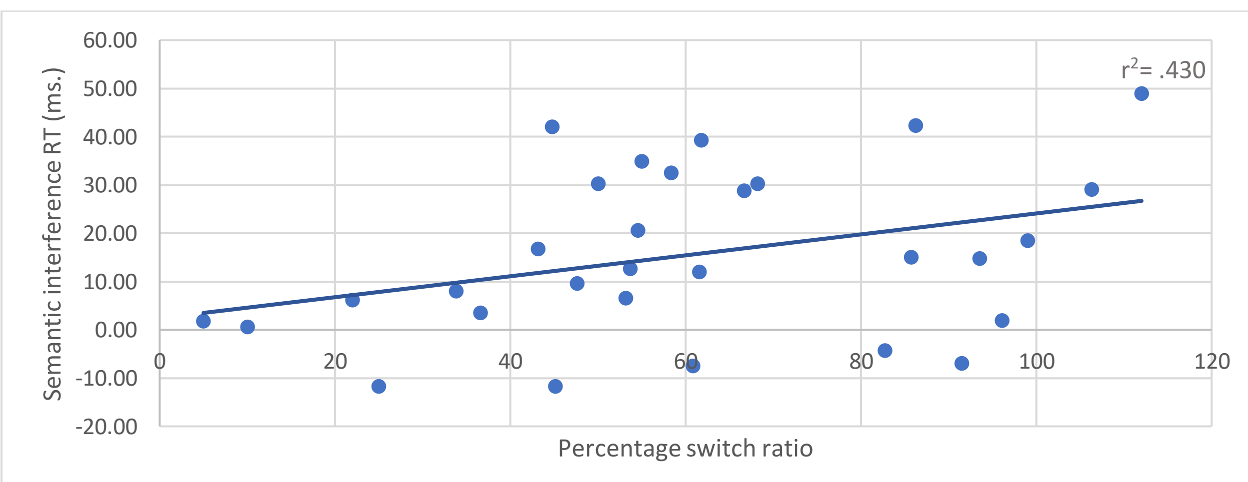


Figure 4.9 Correlation plots for the significant correlation between semantic interference on reaction times and the performance on the digit span task for the healthy older adults.

Finally, two significant correlations were found for the HOA in the trail making task: a positive correlation between the effect of semantic interference on the reaction times (*rs*= .656, *p*<.000) and secondly, on word durations (*rs*= .589, *p*<.001) in picture-naming and the percentage switch ratio. The HOA who demonstrated better shifting abilities, as indicated by lower percentage switch ratios, exhibited less semantic interference as demonstrated by shorter RT and WD in the homogenous conditions as compared to the HOA who exhibited higher percentage switch ratios (indicative on poorer switching ability). The correlation can be seen below in figures 4.10 and 4.11.



Fig*ure 4.10* Correlation plots for the significant correlation between semantic interference on reaction times and the percentage switch ratio for the healthy older adults.

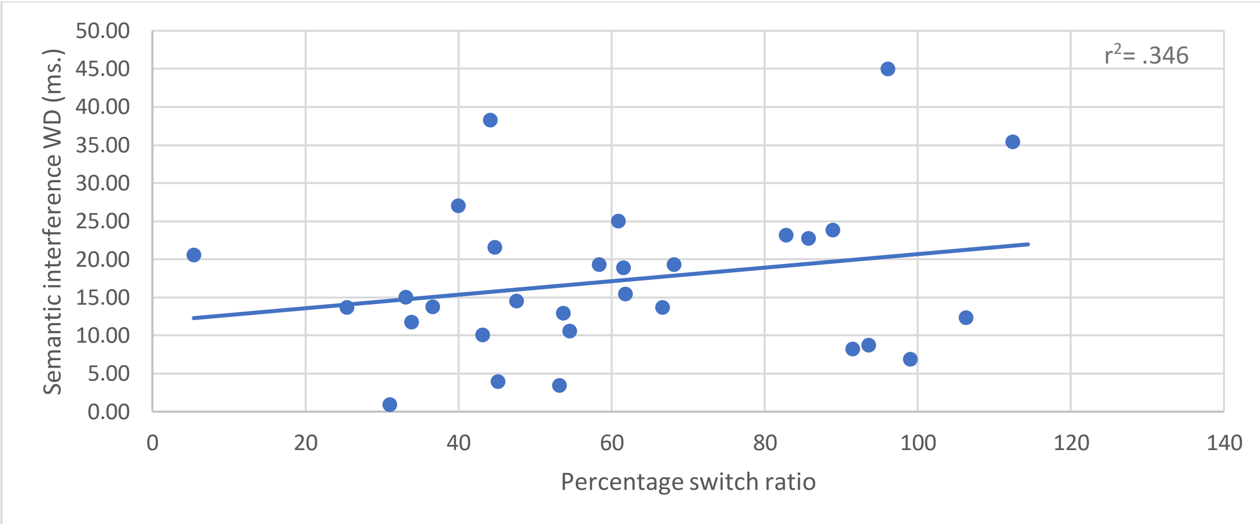


Figure 4. 11 Correlation plots for the significant correlation between semantic interference on word durations and the percentage switch ration for the healthy older adults.

In summary, the HYA failed to exhibit a single significant correlation between the executive control measures and the word production measures. However, the HOA depicted numerous significant correlations between the tasks measuring inhibition (word colour and spatial Stroop), updating (digit span), and switching (trail making), and the RT and WD analyses on the picture-naming task.

4.7 Discussion

A number of studies on language production have provided evidence for the importance of executive control mechanisms in the resolution of semantic interference during lexical access while naming. As discussed in Chapters 2 and 3, when speakers attempt to produce the name of a picture, the names of other semantically related items become activated. The increased activation of semantically related stimuli during the naming of items stimulates a semantic interference effect, which manifests itself in decreased accuracy of naming and longer reaction times (Belke et al., 2005; Schnur et al., 2006). Studies have reported evidence suggesting that executive control mechanisms are involved in the selection process during naming, with inhibition often argued to play an important role (de Zubicaray et al., 2001, 2006; Guo et al., 2011; Roelofs, 2003; Shao et al., 2012).

The present study investigated both healthy younger and older adults in regard to the interaction between executive control processes and the effect of semantic interference on accuracy, RT (linguistic processing), and WD (speech motor control) in a blocked non-cyclic naming task. Following the established theoretical framework of Miyake et al. (2000), executive control was assumed to include inhibiting updating, and shifting abilities, which were assessed using word colour Stroop, spatial Stroop, the N-back, digit span, trail making, and the same-different judgment tasks in this study. For the blocked non-cyclical naming task, measures of semantic interference were calculated as the difference between the homogenous and heterogenous conditions in accuracy, RT, and WD. We predicted that the participants with decreased inhibitory abilities (as measured by the word colour Stroop and the spatial Stroop), lower working memory ability (as measured by the N-back and digit spans tasks) and decreased switching ability (as measured by the trail making and same-different tasks) would show a greater degree of semantic interference in reaction times and word durations, with effects being greater for the HOA. Table 4.5 below provides a summary of the main findings.

Table 4.5: *Results of the Current study of the Correlation between Semantic Interference Effect on Accuracy, Reaction Time, and Word Duration from the Picture-naming Task and Executive Control Measures for the Healthy Younger and Healthy Older Adults*

Executive Function Measures	Healthy younger Adults			Healthy older adults		
	Accuracy	Reaction time	Word duration	Accuracy	Reaction time	Word duration
Inhibitory measures						
Word-colour Stroop						
Percentage Stroop Ratio (%)	-	-	-	-	✓(+)	✓ (+)
Stroop neutral (RT)	-	-	-	-	-	-
Stroop Incongruent (RT)	-	-	-	-	-	-
Spatial Stroop						
Percentage Stroop Ratio (%)	-	-	-	-	✓(+)	-
Stroop neutral (RT)	-	-	-	-	-	-
Stroop Incongruent (RT)	-	-	-	-	-	-
Updating measures						
Digit Span						
Forward digit span	-	-	-	-	-	-
Backward digit span	-	-	-	-	✓ (-)	-
N-back						
1-back (d-prime value)	-	-	-	-	-	-
2-back (d-prime value)	-	-	-	-	-	-
Task switching measures						
Same-Different						
Percentage switch ratio (%)	-	-	-	-	-	-
Same different colour (RT)	-	-	-	-	-	-
Same different final (RT)	-	-	-	-	-	-
Same different switch cost (RT)	-	-	-	-	-	-
Trail Making Test						
Percentage switch ratio (%)	-	-	-	-	✓ (+)	✓ (+)
Trail making A (Time)	-	-	-	-	-	-
Trail making B (Time)	-	-	-	-	-	-
Trail making switch cost (Time)	-	-	-	-	-	-

Note: ✓- significant findings, - non significant findings, +- positive correlation, - negative correlation.

As discussed previously in this chapter, it is well established in the literature that the normal ageing process is often associated with changes in cognition, including executive functions such as declines in inhibitory control (Aoki & Fukuoka, 2010; Skurvydas & Krisciunas, 2013) and processing speed (Park et al., 2002; Salthouse, 1996; Salthouse, 2009). The significant differences in the performance of the healthy younger and healthy older adults in our study validate previous research in this area where the HOA were less accurate, more error-prone, and required an increased amount of time to respond on all the executive control measures, as compared to the HYA who responded faster and exhibited increased accuracy scores.

Moreover, results from this study indicated that the executive control abilities of inhibition, working memory, and switching directly contribute to the speed of reaction times and word durations in the healthy older adults; however, no significant correlations were evident for the healthy younger adults. These findings match the results from the 2008 study by Bialystok, Craik, Luk (2008) where no significant correlations were identified between executive control measures (inhibition and updating of working memory) and measures of lexical access (Boston naming test) for the healthy younger participants. However, their results exhibited significant findings regarding the healthy older adults' executive functioning ability and RT. Both our and their results suggest that executive control processes, specifically inhibitory abilities, are in fact involved in the reduction of the interference caused by the activated semantic competitors during naming. Therefore, it is evident that the inhibitory abilities are in fact involved in lexical access but are manifested differently and to different extents in the healthy younger and healthy older adults. The inhibitory deficits in the healthy older adults could possibly give rise to difficulties in lexical access and lexical selection – this is confirmed in our study, where the HOA who demonstrated a reduction in inhibitory abilities (in the Stroop tasks) equally demonstrated greater difficulty in the resolution of the activated semantically related competitors during naming in the homogenous conditions.

Furthermore, empirical studies have pointed out the overlapping of the specific components of executive control (inhibiting, switching, and updating) with linguistic processes as well as the possible implications of this. Researchers have suggested that inhibiting abilities are associated with lexical selection and word retrieval, specifically resolving competition or lexical ambiguities through the inhibition of the activated non-target lexical items (Novick et al., 2010). However, the influence of the possible interaction between linguistic, speech motor, and executive control processes in healthy younger and healthy older adults is still undetermined.

4.7.1 Association between Inhibitory Measures and Word Production Measures

On the tasks tapping into inhibition - the spatial and word colour Stroop - the healthy older adults demonstrated a positive correlation between the RT measures on the picture-naming task and the percentage Stroop ratio. The participants who exhibited a greater percentage Stroop ratio - thus poorer inhibition - also demonstrated an increase in semantic interference on RT's during picture-naming. That is, the participants who demonstrated poorer inhibitory control on the executive control measures also required an increased amount of time to resolve the activated competing stimuli in the homogenous conditions during picture-naming.

These results mirror previous studies measuring the difference between the performance of healthy younger and healthy older adults in executive control tasks and lexical access (Shao et al., 2015). In a study by Sommers and Danielson (1999), associations between lexical access and inhibitory abilities in healthy younger and healthy older adults were explored. Lexical access was assessed through naming and inhibitory abilities were assessed using the Stroop task. Correlation analyses were conducted to measure the association between inhibitory ability to the scores and reaction times on the language production task. The results indicated a strong significant correlation between the decline in inhibitory ability and the errors and reaction times in the language production tasks for the older adults but not the healthy younger adults. Additionally, in a study by Shao, Janse, Visser, and Meyer (2014), the interaction between executive control processes and lexical access was examined using tasks that tap into inhibition (stop-signal task), updating (operation span) and lexical access (picture-naming) in healthy adults. The results of their study indicated that lexical retrieval speed (RT) influenced the number of words named in both the fluency task and the reaction time speed in the stop-signal task. As such, their results are indicative of the relationship between linguistic processing - specifically lexical access - and inhibitory control.

Moreover, the present study revealed a positive correlation between the percentage Stroop ratio and the effect of semantic interference on WD during picture-naming in the healthy older adults. That is, the HOA who demonstrated smaller Stroop ratios - better inhibitory abilities - were less affected by the semantic interference in the homogenous conditions and demonstrated shorter WD. This is a vital finding as our study was the first to measure the interaction of all three of the following processes: lexical access, speech motor, and executive functioning control. This result demonstrates the imbricated nature of inhibitory abilities, lexical access and speech sound production. This also suggests that healthy older adults, who are at risk of developing weakened lexical retrieval and speech motor processes as discussed in Chapter 2, could be at a higher risk of developing inhibitory deficits.

Results from this thesis (Chapters 2 and 3) and numerous other studies on word production have indicated that semantic interference is manifested by an increase in processing time (RT) needed to resolve the activated competition during lexical access (Levelt et al., 1999; Roelofs, 1997). In addition, results from this chapter provided evidence that all three executive control processes play a role in the inhibition of distractor information and the resolution of semantic interference. Contrary to this, word production models typically focus on the lexical retrieval and lexical selection while concurrently assuming that semantic interference emerges during the lexical access stage (Carr, 1999; Levelt et al., 1999; Starreveld & La Heij, 1996); however, those models fail to elaborate on the means of resolution of the semantic interference effect that occurs during word production (specifically articulation). Therefore, the results from this study provide support that theoretical models of word production ought to include inhibition, updating of working memory, and shifting links within or between linguistic processing levels (Levelt et al., 1999; Starreveld & La Heij, 1996). Moreover, these results suggest that lexical, speech motor, and executive control are not independent, but rather synergetic. Nonetheless, we do acknowledge that the positive correlations that we have acquired are not as significant and robust as we would have desired, therefore further testing would be beneficial. Therefore, future studies should investigate the interaction of all three processes with one another to provide a comprehensive picture of word production in the healthy ageing population.

4.7.2 Association between the Updating of Working Memory and Word Production Measures

From the limited studies that have investigated the interaction between executive control and linguistic processes, results have shown that better working memory leads to smaller semantic interference in reaction time analysis during word production (Belke, 2008; Crowther & Martin, 2014). Our study provides additional support for these results in that the exploratory analysis of the updating of working memory ability revealed a significant negative correlation for the HOA, where the effect of semantic interference on RT during picture-naming was significantly correlated with the backward digit span. The participants who exhibited larger working memory capacities, as evidenced by larger digit spans, also displayed a reduced semantic interference accumulation on RT in the homogenous conditions. Correspondingly, the participants who demonstrated smaller working memory capacities required longer RT in the homogenous conditions. As such, greater working memory was directly associated with the participants' ability to resolve the semantic interference during the naming of items in the homogenous conditions. These results corroborate previous studies on healthy older adults which suggested that the age-related decline in working memory creates increased demands in language processes, resulting in the increased slowing of lexical access as manifested by longer reaction times (Salthouse, 1992; Yardanova, Kolev, Hohnsbein, & Falkenstein, 2004). Similar to our results, Crowther and Martin (2014) revealed that participants in their study who exhibited increased digit spans also exhibited smaller semantic interference. The results from this study furthermore indicate the clear association between executive control abilities and lexical retrieval, where participants who displayed a well-preserved working memory - with larger digit spans - exhibited better abilities in the reaction time analysis for picture-naming. As discussed previously, these results stipulate the inclusion of executive control processes in the resolution of semantic interference during word production in the theoretical word production models.

4.7.3 Association between Shifting Abilities and Word Production Measures

To date, no study has measured the relationship between shifting ability (task switching) and word production measures (lexical access and speech motor control) on healthy younger and/or healthy older adults. In the tasks measuring switching ability, two significant correlations were revealed between the percentage switch ratio and the effect of semantic interference on RT and WD for the HOA. The HOA who demonstrated better switching ability, as indicated by smaller switch ratios, also demonstrated smaller interference effects on the RT and WD in the homogenous conditions during picture-naming. This suggests that shifting ability could contribute to lexical access through its involvement in the reduction of semantic interference during picture-naming. Therefore, future studies should investigate the possible association between shifting ability and lexical access/retrieval.

4.7.4 Conclusion

The results from our study provide further evidence of the vital role executive control mechanisms play in lexical access. Overall, the results from our study corroborate the results from several previous studies on healthy speakers who demonstrated the direct associations between executive control processes and language ability, where the semantic interference observed during single word picture-naming was found to be significantly correlated to executive control processes, specifically working memory and inhibitory control (Belke, 2008; Crowther & Martin, 2014; Shoa et al., 2015). Moreover, our study was the first to measure the interaction between shifting ability and lexical access, of which we have managed to find two significant correlations. To conclude, it is evident that lexical access, specifically the semantic interference occurring during picture-naming, is notably associated with executive control abilities, specifically inhibitory control and the updating of working memory (Belke, 2008; Crowther & Martin, 2014; Shao et al., 2015). Additionally, the results from this study provide support for the inclusion of executive control abilities in word production models, with the concept that executive control mechanisms operate in coordination with linguistic processes in the resolution of semantic interference and lexical access.

Moreover, to date, this study was the first of its kind to measure the influence of all three processes - linguistic, speech motor, and executive control - on healthy younger and healthy older adults. Two significant interactions were found, where all three processes were found to correlate. Namely, manipulations of the linguistic levels (semantic blocking) influenced speech motor control (articulatory word durations), which had a significant correlation with inhibitory ability (percentage Stroop ratio and percentage switch ratio). As discussed in Chapters 2 and 3, the results from our study indicated that the cascade of spreading activation of semantic interference from linguistic levels continues to speech motor levels, evidenced by longer WD on words in the homogenous conditions. These results are indicative of the association between linguistic and speech motor processes. Moreover, this chapter provides further evidence of the cascading information between cognitive (executive control), linguistic, and speech motor processes (Dell,1986; Dell & O'Seaghdha,1991; Harley,1993; Humphreys, Riddoch, & Quinlan,1988). It is evident that additional studies are needed to further explore the relationship between the healthy ageing process on spoken language production and executive control abilities, through investigating the impact of cognitive decline on lexical access and speech motor control. To conclude, theories of word production must take into account the dynamic nature of word production and its interactions with executive functions and speech motor control. In particular, it is imperative that we understand the effects of age on word production, due to the rapidly increasing number of adults over the age of 60 and the increasing prevalence of age-associated neurodegenerative disorders.

Chapter 5

Measuring the Interaction of Linguistic, Speech Motor, and Executive Control processes in Word Production in People with Aphasia

5.1 Abstract

Background:

Neuropsychological studies have shown that alongside speech and language impairments, deficits of executive control commonly occur in people with aphasia. However, knowledge about how these domains interact in people with aphasia is currently limited. The purpose of this study was to investigate the interaction of the three core domains of executive control—inhibiting, switching, and updating— on linguistic and speech motor processes in participants with aphasia.

Aims:

This research has two aims: 1. To determine the difference between the performance of executive control measures between the people with aphasia and healthy controls. 2. To determine the relationship among the effect of semantic interference on the accuracy, RT (linguistic processes), and WD (speech motor performance) and executive control processes (inhibition, updating, shifting) in people with aphasia and healthy controls.

Methods:

Seventeen people with aphasia (Mean= 67.47, SD= 9.94) and 17 age- and education-matched healthy adults (Mean= 63.29, SD= 11.06) completed a battery of executive control tasks that separately tapped inhibiting, switching, or updating. Tasks of inhibition included the word colour Stroop and the spatial Stroop. Tasks of updating of the working memory included the n-back and the forward and backward digit span. Additionally, the tasks measuring task switching included Trail Making Test and the same-different switching task. Correlations were calculated between the performance of the healthy controls and the participants with aphasia on the executive function task and their performance and the effect of semantic interference in the picture-naming task (where semantic interference was calculated as the difference between the accuracy, RT, and WD between the homogenous conditions and the heterogenous conditions).

Results:

Compared to the healthy controls, the participants with aphasia performed significantly slower and with a decreased accuracy, RT, and performance time on all the executive function task as

compared to the healthy controls. The healthy controls demonstrated a positive correlation between a measure of inhibition (spatial Stroop ratio) and the effect of semantic interference on picture naming accuracy. The healthy controls also showed a negative correlation between the backward digit span (measuring updating ability) and the effect of semantic interference on RT. The participants with aphasia demonstrated a positive correlation between the word colour Stroop ratio (measures of inhibition) and the effect of semantic interference on WD. The participants with aphasia also showed a positive correlation between the spatial Stroop ratio and the effect of semantic interference on picture naming accuracy. A negative correlation was also found between the switch ration on the Trail Making Task (measuring switching ability) and the effect of sematic interference on WD during picture naming.

Conclusions & Implications:

These results suggest that the degree to which lexical retrieval is disrupted in tasks such as the picture naming task is possibly modulated by impairments in speech motor control and executive control processes. However, further research is warranted to delineate the nature of the relationship between executive control and word production in PWA. Our findings highlight the importance of considering the broader word production impairment profile of PWA when interpreting language assessments, considering approaches to therapy, and understanding therapy outcomes.

5.2 Introduction

The comprehensive impairment profile for people with aphasia is important yet often overlooked. Emphasis is typically put on language impairments, which disregards the possible implications of the cognitive and speech motor impairments that commonly co-occur in people with aphasia (Cahana-Amitay & Albert, 2014; Villard & Kiran, 2014). Studies measuring linguistic processing and executive control in people with aphasia have consistently reported impaired performance on linguistic and cognitive measures including attention, memory, and executive control (Murray, 2012; Vallila-Rohter & Kiran, 2013). There is a growing body of research from neuropsychological studies documenting the existence of executive control impairments in both the acute and chronic stages of aphasia (El Hachioui et al., 2014; Purdy, 2002); however, uncertainty remains regarding the course of manifestation of those executive control impairments on language processing (Simic et al., 2017). Additionally, current research has recognised the possibility that the communication problems observed in people with aphasia extend beyond the linguistic impairments caused by a faulty linguistic system. Rather, it is the result of the additional cumulative deficits of the speech motor and executive control processes that accompany aphasia (MacPherson & Smith, 2014; Ramsberger 1994, Villard & Kiran, 2017).

As discussed in Chapter 3, studies have proposed that the inhibition of the activated potential competitors is required for the successful retrieval of words. Thus, executive cognitive functions, particularly inhibitory control, are crucial for accurate word production. Despite the fact that word production and linguistic impairments are hallmark features of people with aphasia, the influence of executive control on linguistic functions in people with aphasia has not been sufficiently explored and is not well-established. Additionally, everyday communication requires not only the simultaneous coordination of linguistic and cognitive processes but also the coordination of speech motor processes: this is needed for the accurate sound production of the targeted word. Nonetheless, research has neglected to investigate the possibility of the influence of the impairments in linguistic, speech motor, and cognitive processes on one another, in people with aphasia.

5.2.1 Executive Control Impairments in People with Aphasia

Studies on people with aphasia have detected impairments in cognitive processes including but not limited to: memory, attention allocation, inhibition, processing speed, and sequencing (Keil & Kaszniak, 2002; Murray, Holland, Beeson, 1997; Purdy, 2002). Out of the innumerable cognitive processes, people with aphasia exhibit in particular pronounced difficulty in the specific domains of cognition that fall under the umbrella of executive functioning, such as inhibition, updating of the working memory, and task switching (El Hachioui, Visch-Brink, Lingsma, Van de Sandt-Koenderman, Dippel, Koudstaal, 2013; Helm-Estabrooks, 2002).

The study that prompted further research on the executive functioning abilities of people with aphasia was conducted by Glosser and Goodglass (1990). The researchers administered four experimental executive function procedures to 22 participants with aphasia, 19 participants with right hemisphere brain damage, and 49 age-matched healthy controls. The test procedures included the non-verbal continuous performance test and the Tower of Hanoi to measure the updating of working memory ability and the graphic pattern generation and sequence generation task to measure inhibitory ability. The results of their study indicated that the participants with aphasia were significantly more impaired in all four tasks as compared to the participants with right hemisphere brain damage and the healthy controls. Additionally, the researchers suggested that the observed impairments in the executive control abilities of the people with aphasia were independent of the subjects' linguistic impairments; rather, they were due to the lesions occurring in the left frontal and prefrontal regions of the brain, which are also associated with executive functioning ability.

Research measuring working memory abilities in people with aphasia has provided evidence that participants with aphasia often demonstrate poor updating of working memory abilities on both verbal and non-verbal traditional neuropsychological tests that tap into working memory abilities (Christensen & Wright, 2010; Ivanova, Dragoy, Kuptsova, Ulicheva, & Laurinavichyute, 2015; Ivanova, Kuptsova & Dronkers, 2017; Mayer & Murray, 2012). Ivanova and Hallowell (2014) examined working memory abilities in 27 people with aphasia (eighteen anomic, two conduction, two transcortical motor, five Broca) and 44 age- and education-matched healthy controls. Working memory was measured through a listening span task where the participants were asked to listen to sentences and remember a separate set of words for subsequent recognition. The length and complexity of sentences was manipulated to create four conditions: (a) short and simple sentences; (b) short and complex sentences; (c) long and simple sentences; and (d) long and complex sentences. The four conditions in the listening span task were presented to the participants to enable the investigation of the possible impact of length and syntactic complexity on working memory processes in people with aphasia. Results confirmed that all the participants with aphasia, regardless of type, performed significantly worse on all conditions of the working memory listening span task compared to healthy controls. Moreover, longer and more difficult sentences proved to be more difficult for the participants with aphasia as indexed by their lower processing scores.

Additionally, cognitive inhibitory deficits in people with aphasia have been documented a great deal in the area of neuropsychology, with participants demonstrating significant interference costs in accuracy and increased reaction times as compared to healthy controls (Hamilton & Martin, 2005; Kuzmina & Weekes, 2017; Pompon et al., 2015). A 2013 study by Zakarias, Kereztes, Demeter, and Lukacs investigated the executive functioning abilities of five participants with transcortical aphasia, five participants with conduction aphasia, and five age- and education-matched healthy controls. The experiment included the auditory and visual n-back tasks to tap into the updating of working memory and the stop-signal Stroop and nonverbal Stroop to tap into inhibition. The purpose of using the four targeted non-verbal tasks was to reduce the influence of the impaired linguistic ability commonly occurring in people with aphasia. As opposed to healthy controls, people with aphasia, performed significantly poorer on all four tasks. Additionally, results revealed that the participants with transcortical motor aphasia exhibited significantly more deficits on the stop-signal Stroop task than the participants with conduction aphasia, suggesting that people with transcortical motor aphasia are considerably more impaired in their inhibitory abilities.

To conclude, impairments in cognitive deficits, such as attention, working memory, and executive functioning have been shown to be relatively common in people with aphasia (Beeson, Bayles, Rubens, Kaszniak, 1993; Frankel, Penn, & Ormond-Brown, 2007; Martin et al., 2012). Correspondingly, studies have also revealed that the executive function deficits in people with aphasia have a direct influence on linguistic processes such as lexical-semantic processing

(Martin et al., 2012; Novick, Kan, Trueswell, & Thompson-Schill, 2009) and syntactic processing (Haarmann, Just, & Carpenter,1997; Meteyard, Bruce, Edmundson, & Oakhill, 2015).

5.2.2 Interaction of Executive Control and Linguistic Processes in People with Aphasia

The influence of executive control processes on linguistic processes is detailed in the results from multiple studies on healthy (Taler, Aaron, Steinmetz, & Pisoni, 2010; Roelofs, 2008) and impaired individuals (Engelhardt, Corely, Nigg, & Ferreira, 2010; Montgomery, Magimairaj, &Finney, 2010). Results from those studies have suggested that the specific components of executive control (inhibition, updating of working memory, and switching) are associated with lexical selection and word retrieval, specifically resolving competition or lexical ambiguities through the inhibition of activated competing lexical items (Novick, Trueswell, &Thompson-Schill, 2010). Additionally, neurophysiological research on brain-damaged patients has revealed significant correlations between the decline of inhibitory ability and difficulty with lexical access and word selection (Novick et al., 2010; Badre, Poldrack, Pare-Bagoev, Insler, & Wagner, 2005).

Word production in people with aphasia is often characterised by slow and less accurate lexical retrieval under conditions where there is increased interference from the simultaneous activation of semantic competitors (e.g., cat → dog, tiger, lion) compared to when there are fewer competitors (e.g., harp). This is supported by studies investigating name agreement (Bose & Schafer, 2017; Novick et al., 2009) and semantic blocking (Biegler et al., 2008; Schnur et al., 2006). Executive functioning abilities, particularly inhibitory control, are therefore essential for the accurate and successful lexical selection during word retrieval; however, this ability is often impaired in people with aphasia. Minimal studies on people with aphasia have been conducted to measure the possible correlations between lexical access and executive functioning ability.

In a review article by Martin and Allen (2008), the authors suggested that reduced executive control abilities in people with aphasia, specifically deficits in inhibitory processes, lead to short-term memory deficits. Critically, the article indicated that, in recent and previous research studies, participants with aphasia who perform poorly on semantic short-term memory tasks, such as related judgment tasks, displayed exaggerated interference effects on tasks requiring inhibition, such as the Stroop task (Biegler et al., 2008; Freedman et al., 2004). The article also proposes the possible implications of poor inhibitory abilities in people with aphasia on the proper inhibition of irrelevant competitors, leading to excessive interference. Sequentially, the excessive interference from competing activated stimuli creates a faulty short-term memory, manifested in the incorrect retrieval of words during word production in people with aphasia.

To my knowledge, only two studies in the field of aphasia, Kuzmina and Weekes (2017) and Faroqi-Shah et al. (2016), have correlated the performance of people with aphasia on executive control measures with picture naming abilities. In a 2017 study, Kuzmina and Weekes explored the association between inhibitory abilities, language comprehension, and lexical access on 31 people with aphasia (14 with non-fluent and 17 with fluent aphasia) and 21 healthy controls. The researchers utilised the non-verbal Flanker task and the word-colour Stroop task as measures of inhibition, a picture-naming task as measure of lexical access, and a sentence comprehension task. Dependent measures were accuracy on all four tasks, with the addition of reaction time analysis for the Flanker task. Results indicated that all people with aphasia performed significantly worse than the healthy controls, with the non-fluent participants with aphasia demonstrating decreased accuracy in all cognitive tasks as compared to the fluent participants with aphasia. Significant correlations were found between the reaction times on the Flanker task and accuracy on the sentence comprehension and picture-naming tasks for both groups with aphasia. The researchers additionally reported a significant correlation, for all people with aphasia, between the participant’s accuracy in the Stroop task and their picture-naming ability - where lower naming accuracy was associated with larger Stroop interference. The results from this study corroborated results from previous studies on executive control and lexical access in healthy adults which indicated the significant influence of poor executive control abilities, specifically inhibition, on lexical access (Belke, 2008; Bialystok, Craik, Luk, 2008; Crowther & Martin, 2014; Shoa et al., 2015). These results suggest that the association between executive control processes and lexical access is manifested from the inability to inhibit the irrelevant activated competitors during lexical selection.

Conversely, in a study by Faroqi-Shah et al. (2016), 38 people with aphasia (18 monolingual and 10 bilingual) and 28 age- and education-matched healthy controls (18 healthy monolingual adults and 10 bilingual adults) were tested on a semantic fluency task, picture-naming task, and a verbal Stroop task. For both the semantic fluency task and the picture-naming task, accuracy was the dependent variable. As for the Stroop task, the Stroop difference and Conflict ratio was measured. Stroop difference was calculated as the difference in accuracy/RT between the incongruent and congruent trials and the Conflict ratio was calculated as the accuracy/RT difference between incongruent and congruent trials divided by the congruent trials. As a group, the people with aphasia performed significantly poorer than the healthy controls on all three tasks. However, there were no significant correlations between the Stroop measures and accuracy in the picture-naming task in either the healthy controls or the people with aphasia. It is vital to recognise that both studies only included measures of accuracy for the naming task and measured only inhibition (through the utilisation of the Stroop and Flanker tasks) for measures of executive control. In the present study, we aim to fill the gaps in the literature by measuring the relationship between all three domains of executive control (inhibition, updating of working memory, and task switching) and measuring both reaction time and accuracy as measures of lexical retrieval. Additionally, this study includes a large cohort of measures for each of the executive control domains, such as percentage Stroop ratios, percentage switch ratios, and D-prime measures to precisely detect executive control performance in each of the tasks.

To summarise, it is apparent from previous and recent studies that people with aphasia often exhibit multiple impairments in cognitive, linguistic, and speech motor processes. As all three processes - cognition, linguistic, and speech motor - are required for adequate speech production, it is imperative that researchers consider all three processes of communication in the research of word production in people with aphasia. Current empirical research continues to corroborate the existence of the significant relationship between language processes and executive functioning abilities with impairments in working memory and inhibitory abilities, directly observed in deficits in language abilities in people with aphasia (see Salis, Kelly, & Code, 2015 for a review). However, to date, research on aphasia has not explored the possible associations between executive functioning abilities, specifically, inhibition, updating of working memory, and task switching abilities and their effect on speech motor processes. In order to fully understand speech production in people with aphasia, researchers will need to take into account the multiple levels of language production (cognitive, linguistic, and speech motor) and the interactions between them. This will establish a better understanding of the broader cognitive profile of people with aphasia.

5.3 The Current Investigation, Research Questions, and Predictions

The purpose of the present study is to further our understanding of the possible relationship between linguistic (lexical access/retrieval), speech motor (articulatory performance), and executive control processes in 17 people with aphasia (PWA) and 17 age-matched healthy controls (HC). To explore how lexical and speech motor processes in word production are influenced by updating, shifting, and inhibitory processes, this study utilised the results from the picture-naming task in Chapter 3, where the effect of semantic interference on the measures of accuracy, reaction times (as a measure of lexical access) and word durations (as a measure of speech motor control) were analysed. Executive control was assessed using two individual measures for each of the three targeted sub-domains of executive control: inhibition, updating of working memory, and task switching, based on the Miyake et al. (2000) framework of executive control. The spatial and word colour Stroop were implemented as measures of inhibition, the n-back and digit span task as measures of updating of working memory, and the trail making and the same different tasks as measures of task switching. Reaction times, error rates, Stroop ratio, and the d-prime were measures used for the executive function tasks. Correlation analyses were implemented to determine whether there was in fact a possible association between indicators of executive control abilities and linguistic and speech motor control processes. The research aims and predictions were the following:

> 1-To determine the difference between the performance of executive control measures between the people with aphasia and healthy controls.

Based on the literature, both PWA and healthy controls exhibit impairments in linguistic, speech motor, and executive functioning processes. Therefore, we predict significant differences will be apparent on all executive control tasks between the two groups, with significantly poorer inhibitory control, poorer working memory, and poorer shifting abilities in the PWA.

1- To determine the relationship between the semantic interference effect on RT (linguistic processes), and WD (speech motor performance) and executive control processes (inhibition, updating, shifting) in people with aphasia and healthy controls.

We expect that the executive control measures will correlate significantly with the picture-naming measures from both the PWA and the HC. We predict that there will be vast age differences in the correlation analyses with the PWA exhibiting an increase in semantic interference effects on accuracy, RT, and WD, which will correlate with declines on the variables of measure in the executive control tasks. Specifically, participants with poorer executive control abilities will be affected to a greater degree by the semantic interference effect, as depicted by a decrease in accuracy, longer RT, and longer WD.

5.4 Methods

5.4.1 Participants

The same group of HC and PWA that participated in study 3 (Chapter 3, section 3.4.1) were participants in this study.

5.4.2 Experimental Materials, Design, Procedure, and Outlier Analysis

The experimental materials, design, and procedures were identical to those used in the experiment conducted in Chapter 4. Following one of the most influential frameworks of executive control developed by Miyake et al. (2000), the participants partook in six tasks targeted to measure the three main components of executive control: inhibition, updating of working memory, and shifting (task switching). The tasks conducted were word colour Stroop and spatial Stroop to tap into inhibitory abilities, trail making and the N-back tasks to tap into the updating of working memory, and lastly the digit span and same-different tasks to tap into shifting abilities.

5.4.3 Statistical and Outlier Analysis

Similar to the previous chapter, the Mann Whitney U-test was conducted in order to measure group differences on the executive control measures that were not normally distributed, and the Independent t-test was used on the ones that were. Additionally, Spearman's and Pearson's correlation analyses were performed separately for each group (PWA and HOA) to examine the relationship between the executive control measures (Spatial/word colour Stroop, n-back, digit span, trail making, same-different switching) and the blocked non-cyclical naming measures (effect of semantic interference on accuracy, RT, and WD).

Outlier analysis followed steps from the previous chapter (section 4.5.1). Table 5.1 below provides clarification as to the number of simple and extreme outliers detected in each of the executive function tasks. Appendix 5.1 includes the boxplots used to identify the participants who were expected outliers on the executive function tasks.

Table 5.1: *Number of Simple and Extreme Outliers for the Healthy Controls and People with Aphasia on the Executive Function Tasks*

Executive function task	Healthy Controls		People with aphasia	
	Simple outlier	Extreme outlier	Simple outlier	Extreme outlier
Word colour Stroop ratio	0	0	0	0
Spatial Stroop ratio	0	0	0	0
Backward digit span	0	0	0	0
One back	0	0	0	0
Two back	0	0	0	0
Same different switching ratio	1	0	0	0
Trail Making ratio	2	0	0	0

5.5 Results

The mean and standard deviation values for the executive control tasks for both the PWA and HC are presented in Table 5.1. The findings from the correlation analyses between the executive control measures for each are presented in Table 5.2. Findings for Group differences are presented first, followed by the findings of the executive control measures in both groups.

5.5.1 Group Differences: Executive Control Measures

As can be seen in Table 5.1 below, the two groups (PWA and HC) differed significantly on multiple executive function tasks. However, the PWA and HC demonstrated similar reactions times in both the neutral and incongruent trials on the spatial Stroop task. Additionally, both participant groups performed similarly on the forward digit span and the 1-back. The mean, standard deviation values, d-prime, and accuracy for all the participants (PWA and HC) are presented in Table 5.2.

Table 5.2: *Means, Standard Deviations (SD) for Reaction Time analysis, d-prime, and Accuracy for the HYA and HC participants*

Executive Control Measures	Healthy Controls		People with aphasia		Statistical results
	M	*SD*	*M*	*SD*	
Inhibitory measures					
Word-colour Stroop					
Percentage Stroop Ratio (%)	38.19	10.91	61.99	24.01	**U = -3.70, *p*< .000**
Stroop neutral (RT)	613.48	124.42	1686.04	749.28	**U =-11.01, *p*< .000**
Stroop Incongruent (RT)	887.55	238.99	3338.79	885.03	**U = -3.70, *p*< .000**
Spatial Stroop					
Percentage Stroop Ratio (%)	19.28	17.51	31.478	30.31	**U = -7.964, < .027**
Stroop neutral (RT)	564.99	144.96	643.88	148.16	t (32) = -1.59, *p*= .126
Stroop Incongruent (RT)	690.83	279.47	802.44	252.57	**U** = -1.22, *p*=.231
Updating measures					
Digit Span					
Forward digit span	3.42	1.38	2.74	1.38	t (32) = 1.44, *p*= .159
Backward digit span	2.69	.85	1.62	1.16	**U = 3.08, *p*< .004**
N-back					
1-back (d-prime value)	3.21	1.31	2.74	1.38	t (32) = 1.017, *p*=.317
2-back (d-prime value)	2.56	.833	1.62	1.16	**U = 2.71, *p*< .011**
Task switching measures					
Same-Different					
Percentage switch ratio (%)	65.43	28.15	80.54	20.13	**U = -4.65, *p*< .011**
Same different colour (RT)	766.33	222.98	1012.86	312.23	**U = -2.65, *p*< .012**
Same different final (RT)	1676.58	634.25	2242.16	716.95	**U = -2.44, *p*< .021**
Same different switch cost (RT)	910.18	481.55	1229.30	693.56	**U = -2.96, *p*< .029**
Trail making Test					
Percentage switch ratio (%)	29.24	23.74	72.17	52.39	**U = -5.35, *p*< .002**
Trail making A (Time)	27.59	10.82	53.94	31.98	**t (32) = -3.21, *p* < .003**
Trail making B (Time)	56.82	30.95	126.11	76.68	**U = -3.46, *p*< .002**
Trail making switch cost (Time)	29.24	23.74	72.17	52.38	**U = -3.07, *p*< .004**

Note. U= Mann Whitney

Similar to the previous chapter, accuracy and response times were obtained in all the executive function tasks except for the N-back, digit spans, and Trail Making Tasks. Reaction time analysis was performed after excluding the incorrect responses and outliers. Consistent with prior studies, the percentage Stroop ratio was computed by dividing the difference of the mean of the incongruent trial from the mean of the neutral trial by the mean of neutral and incongruent trials divided by two, and then multiplied by 100. The mean percentage Stroop ratio for the word colour Stroop for the HC was 38.19 and 61.00 for the PWA. On the other hand, the mean percentage Stroop ratio for the spatial Stroop for the HC was 9.65 and 19.28 for the PWA. Smaller percentage Stroop ratios are indicative of better inhibitory abilities.

The range for the forward digit span for the HC was between 4 to 7 with a mean of 3.42 and a SD of 1.32 while the range of digits on the backward digit span was 2 to 7 with a mean of 2.69 and SD of .85. For the PWA the forward digit span ranged from 0 to 5 with a mean of 2.72 and a SD of 1.38 and 0 to 4 digits in the backward digit span with a mean 1.67 of and SD of 1.16.

In the N-back task, the 2-back was of primary interest as it is suggestive of the participant's ability to update the information being presented under pressure. In the 2-back task the HOA had an average d-prime score of 1.25 whereas the PWA was 0.06. As mentioned previously, a higher d-prime indicates that HC were able to perform the task better than the HOA.

In the same-different task, the switching task, and the trail making task, the measure of shifting ability was calculated by the percentage switch ratio. As mentioned previously, smaller percentage switch ratios are indicative of better shifting abilities. The HC demonstrated a mean percentage switch ratio of 65.43 and an SD of 28.15. The PWA demonstrated larger percentage switch ratios with a mean of 80.54 and an SD of 20.13.

In the Trail Making Test, it was evident that the HC were faster to complete both trails as compared to the PWA. The average time it took the HC to complete the trail making task part A was 28.45 seconds and part B was 57.63 seconds while part A took the PWA an average of 78.53 seconds and Part B was 211.21 seconds. None of the HC or PWA participants scored below the cut-off, which was the maximum time of 5 minutes to complete each of the trails. Additionally, as discussed above, the percentage Stroop ratio was the measure of interest in the trail making task. The HC demonstrated a mean percentage switch ratio of 29.24 and an SD of 23.74. The PWA demonstrated larger percentage switch ratios with a mean of 72.17 and an SD of 52.38.

5.5.2 Relationship between the Executive Control Measures and Semantic Interference

Parametric and non-parametric correlations (depending on normality distributions of the executive control tasks) were computed to assess the possible relationship between the executive control abilities (inhibition, updating, and shifting) and semantic interference (the difference between the means of the homogenous and heterogeneous conditions) for naming accuracy, reaction times, and word durations on the blocked non-cyclical picture-naming task. Findings from the correlation analyses between the executive control measures and the picture-naming measures for each of the groups, PWA and the HC, are presented in Table 5.3 below.

Table 5.3: *Statistical Results of the Correlation Analyses for the Executive Control Tasks on the Accuracy and the Semantic Interference on Reaction times and Word Durations from the Picture naming Task for the HOA and the PWA*

Executive Function Measures	Healthy Controls			People with aphasia		
	Accuracy	Reaction times	Word duration	Accuracy	Reaction times	Word duration
			Inhibitory measures			
Word-colour Stroop						
Percentage Stroop Ratio (%)	*rs* = -.113, *p*= .665	*rs* = -.262, *p*= .310	*rs* = .074, *p*= .778	*rs* =.147, *p* = .573	*rs* = -.144, *p* =.595	*rs* = .559, *p* <. 024
Stroop neutral (RT)	*rs* = -.012, *p*=.965	*rs* = -.104, *p*= .691	*rs* = -.034 *p* =.898	*rs* = -.485, *p* <.048	*rs* =.201, *p* = .440	*rs* = -.389, *p* = .123
Stroop Incongruent (RT)	*rs* = 089, *p* = .735	*rs* = -.232, *p*= .370	*rs* = -.167, *p* =.522	*rs* = -.400, *p* =.124	*rs* =.164, *p* =.545	*rs* = -.035, *p* = .897
Spatial Stroop						
Percentage Stroop Ratio (%)	*rs = .546, p* <.023	*rs* = 152, *p* = .560	*rs* = -.145, *p* = .579	*rs* =.514, *p*<.042	*rs* = -.198, *p* =.447	*rs* =.119, *p* = .649
Stroop neutral (RT)	ρ= -.086, *p* =.742	ρ=-.339, *p* = .183	ρ= -.261, *p* = .312	ρ= -.429, *p* = .086	ρ= .195, *p* =.435	ρ= .209, *p* = .422
Stroop Incongruent (RT)	*rs* =.016, *p*= .951	*rs* = -.287, *p* = .265	*rs* = -.208, *p* = .423	*rs* = -.028, *p* = .914	*rs* = -.083, *p* =.752	*rs* =.438, *p* = .078
			Updating measures			
Digit Span						
Forward digit span	*rs* =.487, *p* < .047	*rs* =.264, *p* = .305	*rs* = 108, *p* = .679	*rs* =.271, *p* = .293	*rs* = -.088, p= .736	*rs* = -.252, *p* = .328
Backward digit span	*rs* = .332, *p* = .193	*rs* = -.492, *p* < .045	*rs* =.413, *p* =.099	*rs* =.215, *p* =.408	*rs* = .140, *p* =.593	*rs* = -.346, *p* = .174
N-back						
1-back (d-prime value)	ρ= .423, *p* = .090	ρ= -.048, *p* =.855	ρ= .103 *p* = .694	ρ= .271, *p* = .293	ρ= -.088, *p* = .736	ρ= ,271, *p* = .293
2-back (d-prime value)	*rs* =.404, *p* = .108	*rs* = .363, *p* =.152	*rs* = .284, *p* =.270	*rs* =.251, *p* = .408	*rs* = -.140, *p* =.593	*rs* = -.346, *p* = .174

Executive Function Measures	Healthy Controls			People with aphasia		
	Accuracy	Reaction times	Word duration	Accuracy	Reaction times	Word duration
Task switching measures						
Same-Different						
Percentage switch ratio (%)	*rs* = -.291, *p* = .257	*rs* = -.172, *p* = .510	*rs* = -.395, *p* =.116	*rs* = .260, *p* = .313	*rs* = -.254, *p* = .325	*rs* = -.282, *p* = .274
Same different colour (RT)	*rs* = -.056, *p* = .830	*rs* = -.185, *p* =.479	*rs* = -.135, *p* =.607	*rs* = -.349, *p* = .169	*rs* = -.054, *p* = .837	*rs* = .029, *p* = .911
Same different final (RT)	*rs* = -.468, *p* = .058	*rs* = -.397, *p* = .114	*rs* = -.397, *p* =.114	*rs* =.101, *p* = .701	*rs* =.684, *p* <.002	*rs* = -.449, *p* = .071
Same different switch cost (RT)	*rs* = -.590, *p* < .013	*rs* = -.438, *p* = .079	*rs* = -.407, *p* =.105	*rs* =.159, *p* = .541	*rs* =.650, *p* < .005	*rs* =.478, *p* < .050
Trail making Test						
Percentage switch ratio (%)	*rs* = -.129, *p* = .622	*rs* = -.166, *p* =.524	*rs* = .051, *p* = .844	*rs* = -.425, *p* = .089	*rs* = .012, *p* = .964	*rs* = -.539, *p* <.025
Trail making A (RT)	ρ= .080, *p* = .761	*rs* = -.165, *p* = .527	*rs* = -.088, *p* = .737	*rs* = -.636, *p* < .006	*rs* =.005, *p* = .985	*rs* =.335, *p* = .189
Trail making B (RT)	*rs* = -.071, *p* = .786	ρ= -.185, *p* = .477	ρ= -.246, *p* = .341	ρ= -.556, *p* < .021	ρ= -.262, *p* = .309	ρ= .262, *p* = .309
Trail making switch cost (RT)	*rs* = -.120, *p* = .622	*rs* = -.166, *p* = .524	*rs* = -.539, *p* < .025	*rs* = -.244, *p* = .345	*rs* = -.390, *p* =.122	*rs* =.101, *p* = .701

Note. rs= Spearman's Correlation, ρ= Pearson's Correlation

Similar to the previous chapter, Table 5.3 outlines a comprehensive profile of the results for both the PWA and the HC on all the measures for the executive function tasks. However, the following results and discussion sections will only be reporting on the variables of interest (percentage Stroop ratios, backward digit span, 1- and 2- back, and percentage switch ratios). As per the correlation analysis previewed in Table 5.3, both the healthy older adults and the people with aphasia exhibited multiple significant correlations. The results of the significant findings for the HC and PWA are discussed below.

5.5.2.1 Results for the Healthy Controls. A significant positive correlation (*rs*= .546, *p*<.023) between the naming accuracy in the picture-naming task and the percentage Stroop ratio on the spatial Stroop task was found for the HC group. The HC participants whose naming accuracy was affected to a lesser degree by the semantic interference during the picture-naming task presented greater inhibiting abilities, as shown by smaller percentage Stroop ratios. A scatterplot depicting this relationship can be seen in Figure 5.1 below.

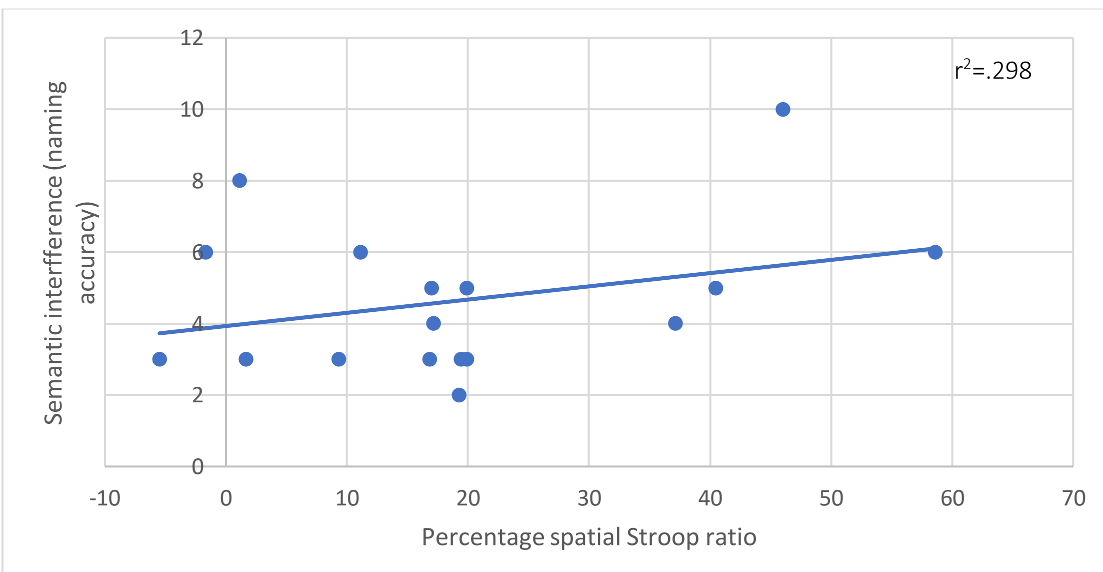


Figure 5.1 Correlation plots for the significant correlation between the effect of semantic interference on naming accuracy and percentage Stroop ratio on the spatial Stroop task for the healthy controls.

Additionally, a negative correlation was also found between the backward digit span task and the effect of semantic interference on reaction times on the picture-naming task with a *rs* value of .492 and significance of *p* <.045. This negative correlation was evident as the HC participants who exhibited larger digit spans (greater updating of working memory ability) displayed smaller semantic interference in RT during picture-naming. That is, participants who demonstrated longer digit spans correspondingly demonstrated shorter RT in the homogenous conditions during picture-naming. Figure 5.2 below displays the correlational relationship.

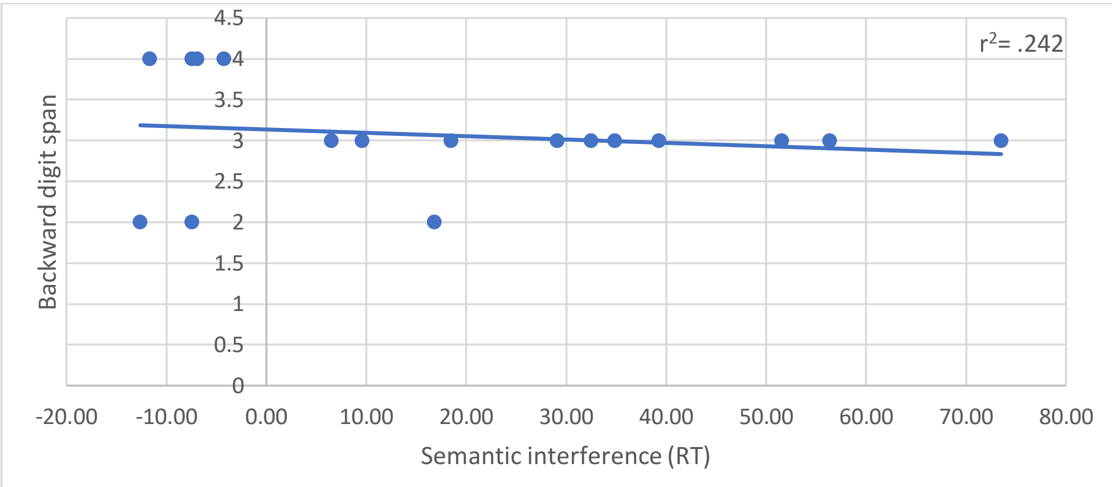


Figure 5.2 Correlation plots for the significant correlation between semantic interference on reaction times and the backward digit for the healthy controls.

5.5.2.2 Results for the People with Aphasia. The statistical analyses for the PWA detected three significant correlations between the executive function tasks with the measures of the semantic interference effect on on the picture-naming task.

A significant positive correlation (rs= .514, p<.042) between the naming accuracy in the picture-naming task and the percentage Stroop ratio on the spatial Stroop task was detected. The PWA participants whose accuracy was greatly affected by the semantic interference, as depicted by negative scores, showed poorer inhibiting abilities as exhibited in larger percentage Stroop ratios. A scatterplot depicting this relationship can be seen in Figure 5.3 below.

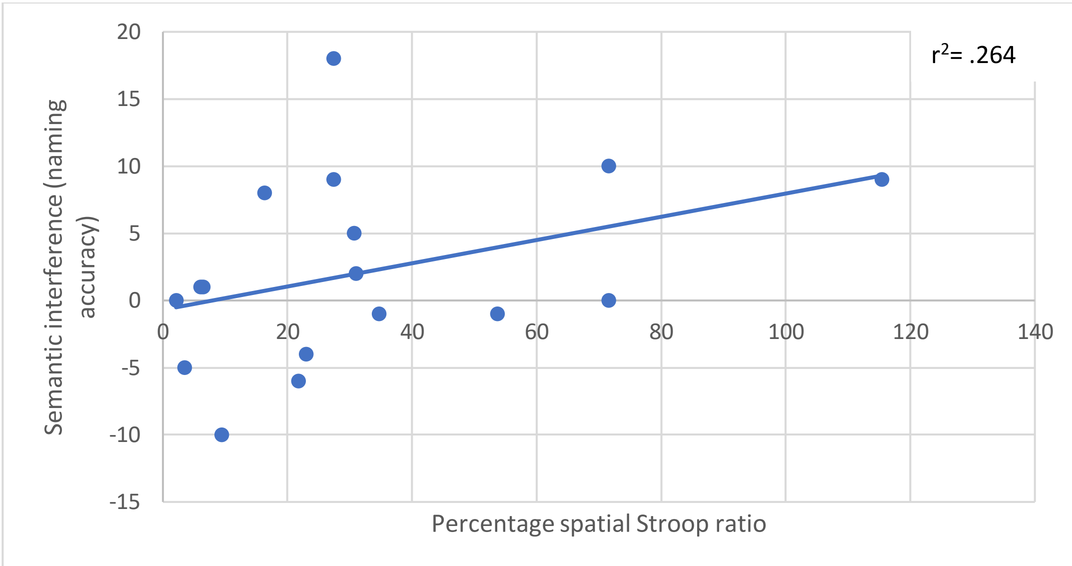


Figure 5.3 Correlation plots for the significant correlation between naming accuracy in the picture naming task and the percentage Stroop ratio on the spatial Stroop task for the people with aphasia.

Additionally, a significant positive correlation (*rs*= .559, *p*<.024) was detected between the effect of semantic interference on word durations and the percentage Stroop ratio on the word colour Stroop task. As indicated above, the PWA participants with higher percentage Stroop ratios on the word colour Stroop task were associated with an increase of semantic interference effect on word duration measures. That is, the PWA who demonstrated poorer inhibitory control on the executive control measure of inhibition correspondingly demonstrated longer WD in the homogenous conditions where inhibitory control is essential in the resolution of the activated competing stimuli. The significant correlation can be seen in Figure 5.4 below.

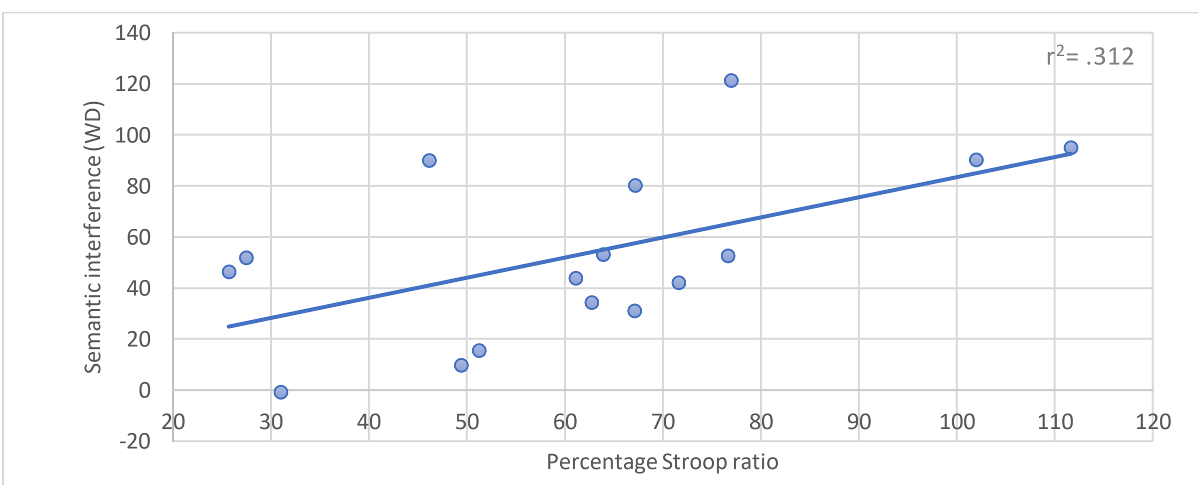


Figure 5.4 Correlation plots for the significant correlation between semantic interference on word durations and the percentage Stroop ratio on the word colour Stroop task for the people with aphasia.

Moreover, one significant correlation was detected (*rs*= .537, *p*< .025) between the effects of the semantic interference on word durations on the picture-naming task and the percentage switch costs on the Trail Making Test. Namely, the PWA with smaller switch costs (better shifting abilities) showed smaller semantic interference effects on the word durations in the picture-naming task, demonstrated by shorter WD in the homogenous conditions than the PWA who exhibited higher switch costs (indicative of poorer switching ability). This correlation can be seen in Figure 5.5 below.

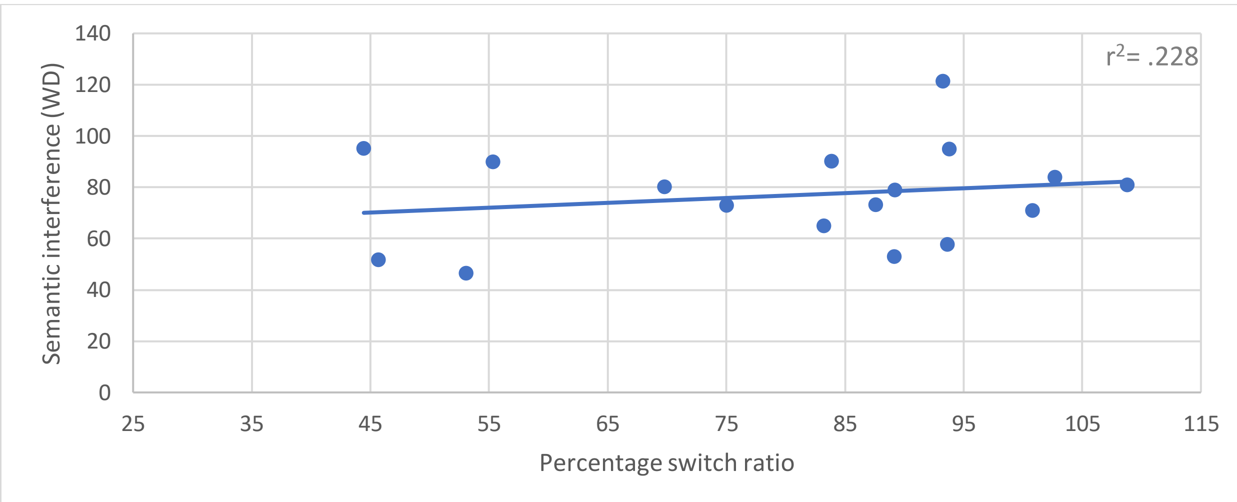


Figure 5.5 Correlation plot for the significant correlation between semantic interference on word durations and the percentage switch ratio on Trail Making Test for the people with aphasia.

In summary, both the PWA and HC demonstrated significant correlations between the executive control measures (inhibition, updating of working memory, shifting) and word production measures (effect of semantic interference on accuracy, RT, WD), with the PWA demonstrating significant correlations between the effect of semantic interference on WD and the percentage Stroop ratio as well as the percentage switch ratio. On the other hand, the HC demonstrated a significant correlation between naming accuracy and the percentage Stroop ratio on the spatial Stroop task, as well as a significant correlation between the effect of semantic interference on RT and the backward digit span.

5.5.3 Case Series Analysis

As discussed previously, studies have indicated that participants with aphasia are heterogenous in nature in regard to their cognitive and linguistic abilities (Marinelli, 2017; Marinelli et al., 2017). However, as can be seen from Table 5.4, the severity of the aphasia and the linguistic deficit seems to be connected to the severity of the executive control impairments in the group of PWA that participated in this study. The group of PWA with mild aphasia (non-fluent and larger AQ scores) demonstrated better executive control performance and were affected to a lesser degree by the semantic interference on the word production measures than the PWA with aphasia that was considered more severe. According to our results and those from previous studies (Kauhanen et al., 2000; Murray, Holland, Beeson, 1997) we can infer that linguistic difficulties and executive control abilities of PWA are strictly related.

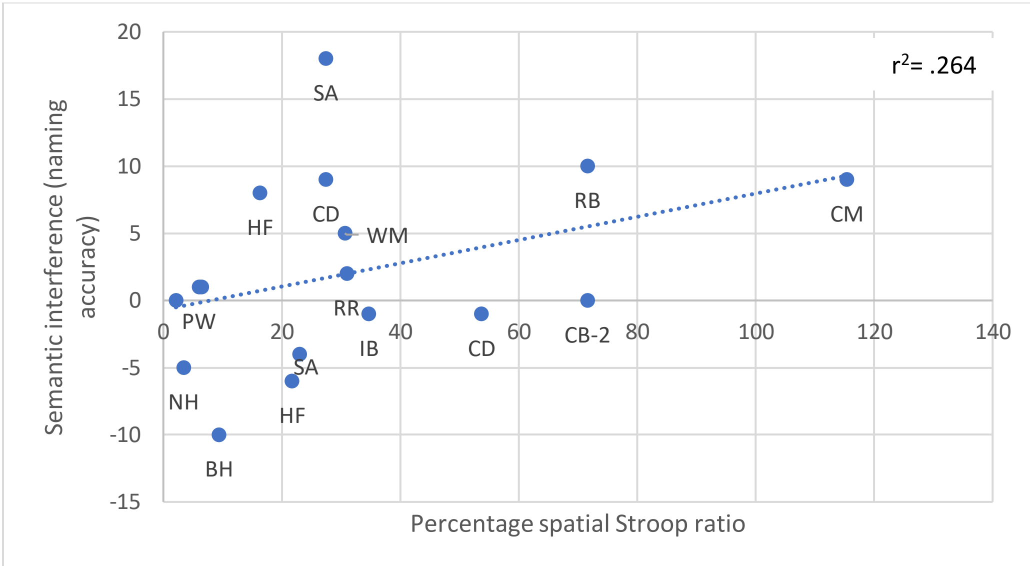
Additionally, the result from the present study indicated that although the group analyses pointed towards a general slowing for the PWA as compared to the HC —a likely consequence of acquired neurological damage from aphasia—there were several individuals with aphasia who performed within normal limits on executive control tasks (see Table 5.4). For these individuals, despite the presence of language impairment, executive control abilities seem to remain intact.

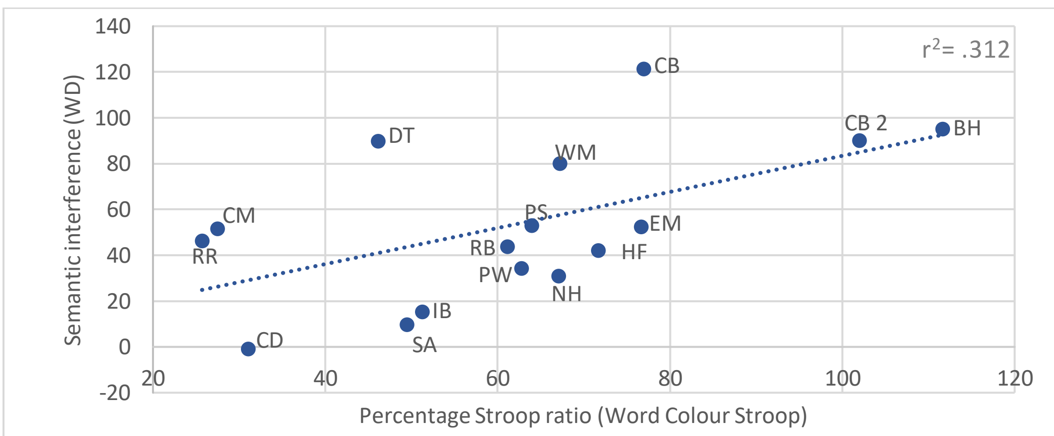
Additionally, on the correlation measures that were found to be significant between the executive control tasks and the measures of word production (see Figures 5.6), three specific PWA (RR, BH, and CM) were performing above average, exhibiting smaller effects of interference on word production measures (accuracy and word durations) and demonstrating superior executive control abilities as indicated by smaller switch ratios (indicative of better switching abilities) and smaller Stroop ratios (indicative of better inhibitory abilities).

Table 5.4: *Individual Level Analysis on Word production and Executive Control Measures for the People with Aphasia*

	Aphasia Type	AQ	Apraxia of Speech	Semantic interference effect			Executive control measures					
				Naming Accuracy	Reaction Time	Word Duration	Word colour Stroop ratio	Spatial Stroop ratio	Backward digit span	2-back	Same different switch ratio	Trail making switch ratio
BH	Anomia	89.4	NA	1	340.69	95.06	76.67	6.06	3	0.36	76.67	93.79
CB	Broca	56.8	✓	-5	232.78	121.32	46.14	23.43	1	1.69	46.14	55.32
CB 2	Broca	58.6	✓	9	250.62	90.07	97.47	27.42	2	1	27.47	45.66
CD	Broca	59.6	✓	0	350.19	73	61.13	71.61	2	0.76	61.13	87.58
CM	Anomia	93.6	NA	9	44.38	51.72	76.95	115.39	4	1.25	76.13	93.23
CW	Conduction	72.9	✓	0	35.68	84.17	71.64	2.11	1	-0.06	71.64	100.83
DT	Anomia	90.2	NA	1	326.41	89.84	67.08	6.46	2	2.99	67.08	108.87
EM	TCM	72.2	✓	-1	164.08	65.2	111.66	34.72	1	0.72	112.34	44.44
HF	Anomia	94.4	NA	-10	567.98	84.99	62.74	9.43	3	2.13	62,74	102.70
IB	TCM	92.8	✓	-4	208.15	71.39	101.96	22.96	3	2.13	101.96	83.87
NH	Anomia	94.2	✓	-6	178.04	31.02	63.91	21.73	4	4.21	63.91	89.16
PS	Conduction	83.6	✓	5	209.4	53.02	25.69	30.64	2	1.64	25.69	53.06
PW	Broca	74.6	✓	-1	299.25	57.81	49.45	53.70	2	2.02	59.45	89.23
RB	Broca	62.4	✓	10	271.77	73.88	NA	71.61	3	-0.15	543.43	93.64
RR	Broca	69.6	NA	2	956.08	46.42	67.18	30.96	3	1.78	67.18	69.77
SA	Anomia	86	✓	8	437.75	79.76	51.23	16.29	4	1.94	51.23	83.21
WM	Conduction	77.8	✓	18	795.87	80.19	31.03	27.42	3	3.16	31.03	75

- Yellow highlight indicative of scores within or above the mean of the healthy controls.





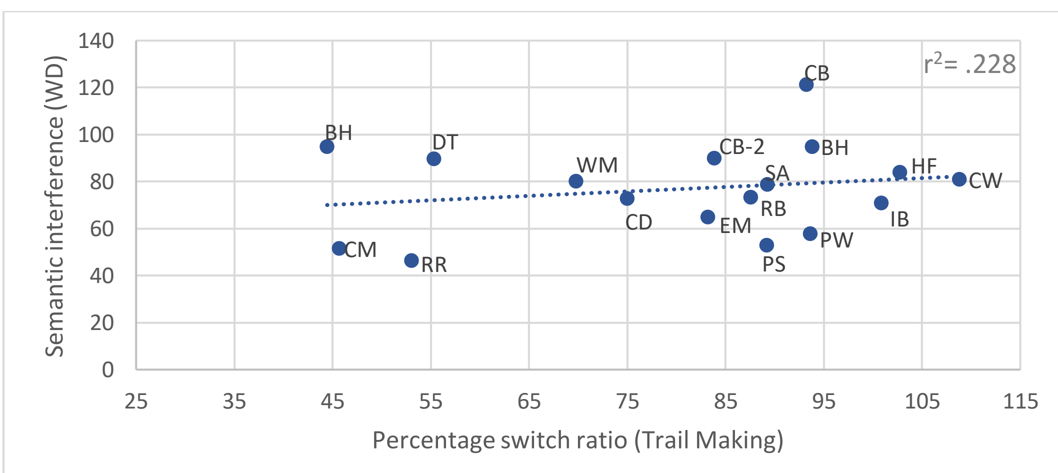


Figure 5.6 Correlation plots for the significant correlation amongst measures of executive control and word production (WD and accuracy) for the people with aphasia.

5.6 Discussion

Several previous studies have suggested that the specific components of executive control (inhibiting, updating of working memory, and shifting) are associated with word production functions. Specifically, many researchers assume that inhibiting abilities are associated with lexical selection and word retrieval, particularly in the resolution of lexical competitions through the inhibition of the activated non-target lexical items (de Zubicaray et al., 2001, 2006; Guo et al., 2011; Novick et al., 2010; Shao et al., 2012).

For individuals with aphasia, word production becomes slower and less accurate under conditions where there are numerous possible alternatives (e.g., desk → counter, table, and worktop) compared to when there are fewer options (e.g., key). This is supported by studies that investigated the effects of name agreement (Bose & Schafer, 2017; Novick et al., 2009) and semantic blocking (Biegler et al., 2008; Schnur et al., 2006) on people with aphasia. However, studies investigating the relationship between word production and executive control processes are limited to heathy adults. To date, there are minimal studies that have investigated the possible implications of the impairments in executive control and their influence on word production abilities in people with aphasia (Kuzmina & Weeks, 2017; Murray, 2012; Villard & Kiran, 2016). Therefore, the current study employed six executive function tasks designed to tap into three executive control abilities - inhibition, updating of working memory, and task switching - with measures of accuracy, speed of performance, RT, and d-prime. The performance of the participants with aphasia on the executive control tasks was correlated to their performance on the blocked non-cyclical naming task (the effect of semantic interference on accuracy, reaction times, and word durations) to better understand the functioning of the word production system and the role of the possible interactions between lexical, speech motor, and executive control processes in single-word production in people with aphasia.

To summarise the main findings, both the healthy controls and the people with aphasia exhibited numerous significant correlations in all three domains of executive control. Table 5.5 below provides a summary of the main findings.

Table 5.5: *Results of the Current study of the Correlation between the accuracy and the Semantic Interference effect on Reaction Time and Word Duration from the Picture Naming Task and Executive Control Measures for the Healthy Older and People with Aphasia*

Executive Function Measures	Healthy older Adults			People with aphasia		
	Accuracy	Reaction time	Word duration	Accuracy	Reaction time	Word duration
Inhibitory measures						
Word-colour Stroop						
Percentage Stroop Ratio (%)	-	-	-	-	-	✓ (+)
Stroop neutral (RT)	-	-	-	-	-	-
Stroop Incongruent (RT)	-	-	-	-	-	-
Spatial Stroop						
Percentage Stroop Ratio (%)	✓ (+)	-	-	✓ (+)	-	-
Stroop neutral (RT)	-	-	-	-	-	-
Stroop Incongruent (RT)	-	-	-	-	-	-
Updating measures						
Digit Span						
Forward digit span	-	-	-	-	-	-
Backward digit span	-	✓ (-)	-	-	-	-
N-back						
1-back (d-prime value)	-	-	-	-	-	-
2-back (d-prime value)	-	-	-	-	-	-
Task switching measures						
Same-Different						
Percentage switch ratio (%)	-	-	-	-	-	-
Same different colour (RT)	-	-	-	-	-	-
Same different final (RT)	-	-	-	-	-	-
Same different switch cost (RT)	-	-	-	-	-	-
Trail making						
Percentage switch ratio (%)	-	-	-	-	-	✓ (-)
Trail making A (RT)	-	-	-	-	-	-
Trail making B (RT)	-	-	-	-	-	-
Trail making switch cost (RT)	-	-	-	-	-	-

✓- significant findings, - non significant findings, + positive correlation, - negative correlation.

In line with previous studies, the participants with aphasia performed significantly poorer than the healthy older adults on all executive function tasks (see Table 5.2). Moreover, the finding of lower Stroop accuracy is consistent with prior research comparing participants with aphasia and healthy controls (de Bruijn et al., 2014; Wiener et al., 2004; Zakarias et al., 2013).

Additionally, the participants with aphasia performed significantly slower than the healthy older adults on all executive control tasks, which is consistent with other studies of performance speed on Stroop trials (de Bruijn et al., 2014; Pompon et al., 2015; Scott & Wilshire, 2010; Wiener et al., 2004; Zakarias et al., 2013) and on tasks measure updating abilities (Purdy, 2002).

Although executive control deficits are frequently identified in aphasia, this is not a universal finding. Some studies measuring executive control abilities in people with aphasia directly acknowledge that executive control impairments observed at the group level are not consistently demonstrated across the case series in people with aphasia (e.g., Murray, 2017; Seniów et al., 2009). Other studies suggest that higher level cognition, including executive control, attention, and reasoning, is sometimes spared in some cases of aphasia (Fedorenko & Varley, 2016; Varley, 2014). Therefore, it is unsurprising that the influence of the impairments in executive control in people with aphasia has not been systematically explored. This study fills the gap in literature through the recognition of the influence of impaired executive control processes on word production, with numerous associations found in the participants with aphasia.

5.6.1 Association between Inhibitory Measures and Word production Measures

As mentioned previously, minimal studies have been conducted to measure the possible association of executive control processes, specifically inhibiting abilities, on lexical retrieval in people with aphasia. Furthermore, the studies that have been conducted utilised merely accuracy scores on the Flanker, Stroop, and naming tasks as measures for the possible association. However, this study utilised measures of both accuracy, reaction time, and the Stroop ratio for measures of inhibition on two versions of the Stroop task - the word colour Stroop task and the spatial Stroop task - and measures of accuracy, RT, and WD to assess word production.

Previous research has revealed that poor inhibitory control contributes to observed language deficits in people with aphasia (see Hula & McNeil, 2008; Martin & Allen, 2008). The findings in the current study provide further evidence supporting the link between lexical-retrieval during word production and inhibitory abilities in both PWA (Kuzmina & Weekes, 2017) and healthy older adults (Sommers & Danielson, 1999; Shao, 2014) where performance on the Stroop task was significantly correlated with picture-naming measures, demonstrating the role of inhibition in resolving lexical-semantic competition during word retrieval. Evidence has also emerged to suggest poor inhibitory control is associated with poor performance on different language tasks where lexical competition is high, such as semantic blocking (Biegler et al., 2008) or the naming of low name agreement items (Bose & Schafer, 2017; Novick et al., 2009). In the current study, high percentage Stroop ratios - indicative of poor inhibitory abilities - were associated with word production measures for both the PWA and the HC. Firstly, the PWA's percentage Stroop ratios were associated with effects of semantic interference on WD during picture-naming. The PWA who demonstrated smaller Stroop ratios - better inhibitory abilities - were less affected by the semantic interference in the homogenous conditions and demonstrated shorter WD. This is a vital finding as our study was the first of its kind targeting to measure the interaction of all three process: lexical access, speech motor, and executive functioning control on PWA. This result demonstrates the association and complex relationship between linguistic (lexical access), speech motor (word durations), and executive control (inhibition) which demonstrates the imbricated nature of inhibitory abilities on lexical access and speech sound production in PWA.

Furthermore, in this study it was revealed that the HC percentage Stroop ratios were correlated with accuracy scores on the picture-naming task. That is, the HC participants who exhibited a greater percentage Stroop ratio - thus poorer inhibitory control - simultaneously demonstrated an increase in semantic interference in naming accuracy during picture-naming, suggestive of the greater effects of semantic interference on naming ability. These results mirror previous studies measuring the effects of executive control processes on language processes in healthy adults. Sommers and Danielson (1999), measured the association between lexical access and inhibitory abilities in healthy adults where lexical access was assessed through naming and inhibitory abilities were assessed with the Stroop task. Correlation analyses were conducted to measure the association between the participants' inhibitory abilities, as assessed through the Stroop task, to their naming accuracy and reaction times on the language production task. The results from their study indicated a strong significant correlation between the decline in inhibitory ability to the naming accuracy and reaction times on the language production task. Hence, the results from this study and similar previous studies on healthy adults (Hasher &

Campbell, 2013; Salthouse, 2010) are suggestive of the significant contribution that inhibitory control/abilities has in the success of word retrieval, through the inhibition of non-target representations in order to resolve competition, and thus produce the targeted word.

To conclude, results from this chapter as well as the previous one (Chapter 4 section 4.8.1) provided supporting evidence that executive control abilities, specifically inhibition, updating of working memory, and switching are associated with the resolution of semantic interference during word production. These findings provide additional support for the inclusion of executive control processes in or within linguistic processing levels of word production models (Levelt et al., 1999; Starreveld & La Heij, 1996). Additionally, these results suggest that lexical, speech motor, and executive control are not independent, rather that they are synergetic processes that rely on each other for the impeccable execution of word production.

5.6.2 Association between the Updating of Working Memory and Word Production Measures

In regard to updating abilities, several studies have revealed associations between reduced working memory abilities and poor language comprehension in PWA (Caspari et al., 1998; Ivanova et al., 2015, 2017; Leff et al., 2009; Meteyard, Bruce, Edmundson, & Oakhill, 2015; Wright et al., 2007), however no study has measured the association between updating abilities and word production in PWA. Therefore, this study utilised two tasks to measure updating abilities (N-back and digit span) as well as measures of accuracy, RT, and WD to assess word production. In the current chapter, updating of working memory as indexed by the performance in the n-back task was not associated with any measures of word production.

However, the results from this study did demonstrate correlations between the digit span and the effects of semantic interference on accuracy and RT measures during picture-naming for the HC. The HC participants who exhibited larger working memory capacities as evidenced by larger digit spans also displayed a reduced semantic interference effect on naming accuracy and RT in the homogenous conditions. Correspondingly, the participants who demonstrated smaller working memories required longer RT and experienced a decrease in accuracy in the homogenous conditions. Namely, greater working memory was directly associated with the participant’s ability to resolve the semantic interference during the naming of items in the homogenous conditions. The findings of the current study are in line with numerous previous studies on healthy adults that have demonstrated the association between working memory and word production, specifically lexical access and lexical retrieval (Salthouse, 1992; Yardanova, Kolev, Hohnsbein, & Falkenstein, 2004). In regard to HC, the results from this study and the previous study (Chapter 4) furthermore indicate the clear association between executive control abilities and lexical retrieval where participants who displayed a well-preserved working memory - with larger digit spans - exhibited better abilities in the RT during picture-naming.

As discussed previously, there was no correlation between the updating abilities of the PWA and the word production measures. As the current study is the first of its kind measuring the association between updating abilities and word production in PWA, further research would be needed to delve deeper into the possible role of updating abilities in word production.

5.6.3 Association between Shifting Abilities and Word Production Measures

To our knowledge, no study to date has measured the association between shifting ability (task switching) on either or both linguistic and speech motor processes in people with aphasia. However, in our study, on the tasks measuring switching ability, a significant correlation was revealed between the effect of semantic interference on WD and the percentage switch ratio on the trail making task for the PWA.

The PWA who demonstrated an increase in percentage switch ratios (i.e., poorer switching abilities) were correspondingly affected to a higher degree by the effect of semantic interference on WD during picture-naming in the homogenous conditions compared to the participants who demonstrated smaller switch costs, also demonstrating a smaller semantic interference effect and WD (shorter WD) in the homogenous conditions during picture naming. This finding is suggestive that shifting ability contributes to lexical access through the involvement in reducing semantic interference during picture-naming. Additionally, this finding is indicative of the imbricate nature of all three process (linguistic, speech motor, and executive control) during word production in PWA.

Therefore, the findings of this study provide vital new evidence about the complex relationships between executive control abilities and word production, with executive control abilities playing a prominent role in various aspects of language production such as lexical access and lexical selection in people with aphasia. To conclude, future studies should investigate the possible association between shifting ability, lexical access/retrieval, and speech motor control during word production for people with aphasia.

5.6.4 Conclusion

In conclusion, previous studies on word production and semantic interference have provided evidence for the role of executive control mechanisms in the regulation of the activation of semantic competitors during naming in HC (Crowther & Martin, 2014; Helm-Estabrooks, 2002; Shoa, Janse, Visser & Meyer, 2014; Shao et al., 2013; Scott& Wilshire, 2010; Hsu& Novick, 2016) and PWA (Kuzmina & Weeks, 2017; Faroqi-Shah et al., 2016). The studies mentioned above have demonstrated associations between performance on executive control tasks measuring inhibition and the updating of working memory on specific components of language ability.

Moreover, there is growing empirical concern among aphasiologists that non-linguistic aspects of cognition, specifically executive control processes, may contribute to or exacerbate observed language deficits in individuals with brain injuries (Keil & Kaszniak, 2002). The results from our study provide evidence of the vital role executive control mechanisms play in lexical access/retrieval, where the participants in our study who demonstrated poor executive control abilities correspondingly performed poorly on the naming task as compared to the participants who demonstrated better executive control abilities. This finding is suggestive that executive control processes play an important role in the success of impeccable communication through the inhibition of semantic competitors during lexical access/retrieval for both HC and PWA. Specifically, our study corroborates the results of previous studies where inhibiting ability is associated to lexical-retrieval, suggestive that poor inhibitory ability leads to a failure in the inhibiting of the activated non-target competing lexical responses which furthermore contributes to the impaired lexical-retrieval in HC and PWA (Belke, 2008; Crowther & Martin, 2014; Kuzmina & Weeks, 2017; Shoa et al., 2015).

Furthermore, the most vital finding of the present study is the interplay detected between the linguistic, speech motor, and executive control processes in the HC and PWA. We found that the participants in this study who performed poorly on executive control processes simultaneously had longer word durations in the homogenous conditions during picture-naming. This therefore demonstrates the importance of considering the influence of executive control processes on speech motor processes in HC and PWA.

Findings from Chapters 2, 3, and 4, indicated that the cascade of spreading activation of semantic interference from lexical levels continues to speech motor levels, evidenced by longer WD on words in the homogenous conditions. These results are indicative of the association between lexical and speech motor processes. Moreover, this chapter provides further evidence of the cascading information amongst cognitive (executive control), linguistic, and speech motor processes (Dell,1986; Dell & O'Seaghdha,1991; Harley,1993; Humphreys, Riddoch, & Quinlan,1988).

Lastly, our findings highlight the importance of considering the broader word production impairment profile of PWA when interpreting language assessments, considering approaches to therapy, and understanding therapy outcomes. These results suggest that the degree to which lexical retrieval is disrupted in tasks such as the picture-naming task (Shao et al., 2013) is modulated by impairments in speech motor control and executive control processes. Nonetheless, we do acknowledge that the positive correlations, specifically that for the participants with aphasia, which we have acquired are not as significant and robust as we would have desired, therefore further testing would be beneficial. Specifically, further research is warranted to delineate the nature of the relationship between executive control and word production in PWA.

Chapter 6

General Discussion

6.1 Overall Summary

Aphasia is commonly defined as an impairment of language, affecting the production and comprehension of speech and the ability to read or write (McNeil & Pratt, 2001). These traditional definitions presume that the impairment caused by aphasia is purely linguistic with little or no emphasis on the possible manifestation of the symptoms of speech motor deficits in individuals with aphasia. However, current literature has identified the significance of the co-existence of speech motor and linguistic deficits in aphasia, also mentioning the probability that the reduced verbal output and telegraphic speech in individuals with aphasia is the manifestation of that co-existence (J. Duffy, 2016).

Additionally, recent research that has focused on uncovering the linguistic nature of aphasia has increasingly recognised the fact that linguistic processes or impairments alone do not account for impairments in word production (Fridriksson et al., 2006; Geranmayeh et al., 2014; Keil & Kaszniak, 2002; Kuzmina & Weekes, 2017; Simic et al., 2017). Findings from studies on individuals with aphasia have shown that the broader cognitive abilities of said individuals influence the way the linguistic impairment manifests itself (Cahana-Amitay & Albert, 2015).

Moreover, there is evidence that linguistic and executive control processes are linked in healthy children (Nip & Green, 2012), healthy older adults (Sadagopan & Smith, 2013), as well as impaired children and adults (Kleinow & Smith, 2000; Maner, Smith, & Grayson, 2000; Sadagopan & Smith, 2008; Walsh & Smith, 2011). Additionally, empirical evidence from studies on healthy and impaired children and adults has provided confirmation of the possible associations between linguistic and speech motor processes (Dromey et al., 2014; Sadagopan & Smith, 2013). Despite the evidence that all three processes - linguistic, speech motor, and executive control processes - are often affected in healthy older adults and people with aphasia, there has been little to no exploration of the influence and possible interactions of all three processes on people with aphasia. This thesis systematically addresses the possible associations between the three processes through the investigation of: (a) the interaction between linguistic and speech motor processes in word production in healthy younger and healthy older adults (Chapter 2) as well as people with aphasia (Chapter 3), and (b) the relationship between linguistic, speech motor, and executive control processes in healthy younger and healthy older adults (Chapter 4) and in people with aphasia (Chapter 5).

The current research was divided into Phase I (Chapters 2-3) and Phase II (Chapters 4-5). In Phase I, we examined the interaction between linguistic and speech motor processes in healthy younger adults, healthy older adults, and people with aphasia. We recruited 60 healthy, right-handed, monolingual British adults for Chapter 2 (30 healthy younger and 30 healthy older adults) and for Chapter 3 we recruited 17 individuals with aphasia and 17 age- and education-matched healthy older adults. The participants partook in a picture-naming task with experimental manipulations of semantic contexts during lexical access as a measure of linguistic processing and articulatory complexity as manipulation of speech motor performance. Accuracy, RT and WD were measured to investigate the possible interactions between linguistic and speech motor processes, and the possible differences between healthy young and healthy older adults, as well as people with aphasia.

In Phase II, we investigated the relationship between linguistic, speech motor, and executive control processes in healthy younger adults, healthy older adults, and people with aphasia. The same participants in Chapters 2 and 3 participated in the two studies in Chapters 4 and 5. The participants performed six executive control tasks, tapping into inhibition (word colour and spatial Stroop), updating of working memory (N-back and digit span), and shifting abilities (Trail Making Test and same different switching). The performance of the participants in the word production task (picture-naming task in Chapters 2 and 3) was compared to their performance on the six executive control tasks to determine the association among linguistic, speech motor, and executive control processes.

6.2 Review and Contributions of the Experimental Chapters

In this section, a summary and discussion of the results from the preceding chapters will be provided. The implications of this study for clinical and theoretical research on people with aphasia and healthy older adults will also be outlined. This chapter will conclude with a discussion of the limitations of the current dissertation and suggested future directions. Table 6.1 below summarises the findings from the experimental studies in both Phase I and Phase II.

Table 6.1: *Summary of the Findings from the Experimental Chapters*

Chapter 2. Measuring the Interaction of Linguistic and Speech Motor Processes During Picture Naming in Healthy Younger and Healthy Older Adults	
Specific research questions	**Results**
1-To investigate the influence of manipulations to the linguistic and speech motor processes on the performance of HOA and HYA on a picture naming task, on the following variables: Accuracy Reaction time (RT) and Word duration (WD)	• Overall, the HOA performed worse compared to the HYA on the picture naming task as is shown in accuracy, RT, and WD measures. • Linguistic manipulations, as in semantic contexts, significantly influenced linguistic (RT) and speech motor processes (WD). • Speech motor manipulations, as in articulatory complexity, significantly affected accuracy, linguistic (RT), and speech motor processes (WD). • No significant interactions were detected.
Chapter 3. Measuring the Interaction of Linguistic and Speech Motor Processes During Picture Naming in Aphasia	
Specific research questions	**Results**
1-To investigate the influence of manipulations to the linguistic and speech motor processes on the performance of PWA and HC on a picture naming task, on the following variables: Accuracy Reaction time and Word duration 2- Does the fluency of speech in PWA (fluent vs non-fluent) effect the influence of linguistic and speech motor processes? 3- Does the influence of linguistic and speech motor processes depend on the individual participant characteristics in PWA?	• Overall, the PWA performed worse compared to the HC on the picture naming task as is shown in accuracy, RT, and WD measures. • PWA were significantly affected by the manipulations to both the linguistic and speech motor processes. • Linguistic and speech motor manipulations significantly affected linguistic (RT) and speech motor processes (WD). • An interaction between linguistic and speech motor processes was evident in PWA. This interaction was detected for WD rather than RT which is indicative that the interaction between linguistic and speech motor processes was occurring at the speech motor level rather than the lexical/semantic processing level. • Subsequent analysis between fluent and non-fluent PWA revealed that the non-fluent PWA were affected to a higher degree than the fluent PWA by the linguistic and speech motor manipulations on accuracy, RT, and WD. • Individual level analysis revealed that regardless of type and severity of aphasia, linguistic and speech motor control is affected.
Chapter 4. Measuring the Interaction of Linguistic, Speech Motor, and Executive Control Processes in Word Production Healthy Younger and Older Adults	
Specific research questions	**Results**
1-To determine the difference between the performance of executive control measures between the healthy younger and healthy older adults. 2-To determine if there is a relationship amongst the semantic interference effect on RT (linguistic processes), and WD (speech motor performance) and executive control processes (inhibition, updating, shifting) in healthy younger and older adults.	• The HOA performed significantly worse the HYA on all six measures of executive control. • The HOA whom demonstrated better inhibitory, updating, and shifting abilities were affected by the semantic interference to a lesser degree. • The HOA displayed two significant positive correlation between inhibitory control and the effect of semantic interference on RT and WD during picture naming, a negative correlation between working memory ability and the effect of semantic interference on RT during picture naming, and two positive correlations on measures of shifting ability and the effect of semantic interference on RT and WD during picture naming. No significant correlations between the executive control and word production measures for the HYA.
Chapter 5. Measuring the Interaction of Linguistic, Speech Motor, and Executive Control Processes in Aphasia	
Specific research questions	**Results**
1-To determine the difference between the performance of executive control measures between the people with aphasia and healthy controls. 2-To determine if there is a relationship amongst the semantic interference effect on RT (linguistic processes), and WD (speech motor performance) and executive control processes (inhibition, updating, shifting) in people with aphasia and healthy controls.	• PWA performed significantly slower and with a decreased accuracy on all the executive function task as compared to the HC. • PWA and HC whom demonstrated better inhibitory, updating, and shifting abilities were affected by the semantic interference to a lesser degree. • The PWA displayed a significant positive correlation between inhibitory control and the effect of semantic interference on WD during picture naming, a positive correlation between inhibitory control and the effect of semantic interference on picture naming accuracy, and a negative correlation on the measure of shifting ability and the effect of semantic interference on WD during picture naming.

6.2.1 Phase I

As discussed above, Phase I, which consists of Chapters 2 and 3, explored the interaction between linguistic and speech motor processes in healthy younger and healthy older adults as well as people with aphasia, using a non-cyclical picture-naming paradigm with manipulations of semantic context as a measure of linguistic processing and articulatory complexity as a measure of speech motor processes.

6.2.1.1 Findings in Chapter 2. In Chapter 2, the aim was to systematically investigate the effect of normal ageing on linguistic and speech motor control processes. Group differences were analysed for accuracy, linguistic processing speed (RT), and speech motor performance (WD) in the naming responses. A number of previous studies have associated the natural process of ageing with an expected decline in linguistic, cognitive, motor, and sensory functions, accompanied by brain atrophy and neural loss (Park, 2002; Reuter-Lorenz & Lustig, 2005; Salthouse, 1996, 2009). However, minimal studies have measured the effect of ageing on the interaction of linguistic and speech motor processes where their findings demonstrated that factors which might influence linguistic processing can also modulate speech motor aspects of the word that is ultimately being produced (Dromey et al., 2014; Sadagopan & Smith, 2013).

Findings of our study support those of previous studies where the HOA participants were significantly affected by manipulations of both linguistic and speech motor processes, instigating a reduction in naming accuracy, longer RT, and longer WD as compared to the HYA. Those findings provided additional data to the existing literature on ageing, lexical access, and linguistic processing, where the manipulation of linguistic variables, specifically semantic context, manifested itself in a decrease in accuracy and longer RT’s for words in the semantically blocked (homogenous) conditions for both the HYA and HOA (Belke et al., 2005; Damian and Als, 2005; Harvey & Schnur, 2016). Moreover, manipulations at the speech motor level instigated a decrease in accuracy and longer WD for the articulatory complex words, similar to previous studies measuring speech motor processes (Bilodeau-Mercure et al., 2015; Munson, 2007; Sadagopan & Smith, 2013).

Outstandingly, this study provided vital new information as it is the first study to systematically measure the influence of manipulations of linguistic and speech motor processes on linguistic processing and speech motor performance using temporal measures. Manipulations of linguistic processes at the semantic level influenced speech motor performance, where WD's were longer on the words in the semantically blocked contexts. Additionally, manipulations of the speech motor processes directly influenced linguistic processing, where articulatory complex words required longer RT than the simpler ones. The investigation of the interactions between linguistic and speech motor processes in healthy ageing adults is vital, as it has the potential to better our understanding of the speech deficits in disordered speakers by clarifying and distinguishing which changes may be attributed to the typical ageing process itself and which reflect a communication disorder. As there is a paucity of research that focuses on the influence of the interaction between linguistic and speech motor control processes in healthy older adults (except for their inclusion as age-matched controls), this chapter addressed this limitation by including both healthy younger and healthy older adults in the study.

6.2.1.2 Findings in Chapter 3. In Chapter 3, the aim was to determine the interaction between linguistic and speech motor processes in people with aphasia. This chapter proposed three research questions. Firstly, do manipulations of linguistic and speech motor processes influence the performance of PWA and HC in a picture-naming task? Similar to Chapter 2, a wide range of variables – including accuracy, RT's, and WD's – was implemented to measure the interaction of linguistic and speech motor processes on a blocked non-cyclical picture-naming task, using stimuli in different semantic contexts (homogenous vs heterogeneous) while varying articulatory complexity (simple vs complex). Findings from our study demonstrated that both the HC and PWA were affected by manipulations of both the linguistic and speech motor processes, where the manipulations of these processes instigated a reduction in naming accuracy, longer RT, and longer WD. However, the PWA were affected to a significantly greater degree by the manipulations. These results were similar to those from studies measuring the effects of manipulations of linguistic and speech motor processes on HC and PWA; however, those studies measured the manipulations of linguistic and speech motor processes separately and independently (Hillis, Rapp, Romani & Caramazza, 1990; Jefferies & Lambon Ralph, 2006). Similar to Chapter 2, the findings from our study provided additional data to support the existing literature on PWA, lexical access, and linguistic processing where the manipulation of linguistic variables, specifically semantic context, induced a decrease in accuracy and longer RT's for words in the semantically blocked (homogenous) conditions for both the PWA and HC (Belke et al., 2005; Schnur et al., 2006, 2009; Novick et al., 2009). Furthermore, manipulations at the speech motor level instigated a decrease in accuracy and longer WD for the articulatory complex words, similar to the results of previous studies measuring speech motor processes (Adam, 2013; Baum, 1993; Bose et al., 2007).

Significantly, as in Chapter 2, this study provided vital new information as it is the first to measure the influence of linguistic and speech motor processes during naming in PWA. As in the previous chapter, the manipulations of linguistic processes at the semantic level influenced speech motor performance, where WD's were longer on the words in the semantically blocked contexts. Moreover, manipulations of the speech motor processes directly influenced linguistic processing, where articulatory complex words required longer RT than the simpler ones. Most importantly, an interaction between the linguistic (semantic context) and speech motor performance (articulatory complexity) was detected in this study for the PWA. This interaction was exhibited in longer WD for complex words in the semantically blocked homogenous conditions, compared to the same words in the heterogeneous conditions. Specifically, this interaction was detected for WD rather than RT, which suggests that the interaction between linguistic and speech motor processes was occurring at the speech motor level rather than the lexical/semantic processing level.

The second research question read as follows: does the type of aphasia (fluent vs non-fluent) affect the influence of linguistic and speech motor processes during picture-naming? The results from this experiment revealed differences between the fluent and non-fluent PWA in linguistic and speech motor processing. The non-fluent PWA generally exhibited longer RT and WD compared to the fluent PWA (McCarthy & Kartsounis, 2000; Robinson, Shallice & Cipolotti, 2005; Wilshire & McCarthy, 2002). Additionally, an interaction between blocking and complexity was discovered in the non-fluent PWA participants, where complex words in the homogenous conditions exhibited longer WD, compared to when the same words were presented in the heterogeneous conditions.

Finally, does the influence of linguistic and speech motor processes depend on the individual participant characteristics in PWA? Findings from the study revealed that regardless of aphasia type, severity, and diagnosis, as a whole the PWA participants were significantly affected by manipulations of linguistic and speech motor processes, displaying significant impairments in linguistic processing and speech motor performance.

6.2.1.3 Significant contributions to literature of Phase I. The findings reported above provide vital empirical evidence that linguistic characteristics of utterances directly influence speech motor performance and contrariwise, thus substantiating the dynamic interaction between those processes and the influence they have on one another.

To elaborate, most models of spoken word production agree that word production involves a number of processing stages, namely a conceptual level, a lexical-semantic level, and a phonological-speech motor preparation level (Dell, 1986; Levelt et al., 1999). Those models also generally agree that during the lexical access of a target word (e.g., *dog*), semantically related words are simultaneously activated as competitors (e.g., *cat, wolf, tiger*) (Dell, 1986; Caramazza, 1997; Levelt et al., 1999; Goldrick & Rapp, 2002; Indefrey, 2011). Numerous studies investigating word production and lexical access have found that the activated competitors from the same semantic category (e.g., '*cat, wolf, tiger'* as competitors for the targeted word '*dog'*) cause naming reaction times to become longer. This increase in naming reaction time is also known as the "semantic interference effect" (Glaser & Dungelhoff, 1984).

Congruently, previous research studies that have utilised picture-naming experiments with manipulations of the semantic contexts typically show that repeated access to the same semantic category induces a semantic interference effect. This interference is thought to arise during the selection of a target entry from co-activated semantically related lexical entries (Abdel Rahman & Melinger, 2011; Belke, 2008; Schnur, Schwartz, Brecher, & Hodgson, 2006). Importantly, previous research assumes that the semantic interference effect is situated at the lexical level; however, the results from both Chapter 2 and 3 indicate that the effect of semantic interference extends beyond linguistic levels of word production and influences the speech motor performance and executions of the targeted word. In our studies, manipulations of the linguistic variables induced longer WD's - specifically, words in the semantically blocked contexts (homogenous conditions) influenced speech motor performance as depicted by longer WD's. This finding demonstrates that alterations to the linguistic levels extend and influence lower processing levels such as speech motor performance. More precisely, the effect of linguistic complexity on word duration highlights the notion that as linguistic demands increase, speech motor systems must also be adjusted in order to accommodate those increases. This discovery is a unique and vital finding which extends the literature and word production models concerning the dynamic relationship and the influence of linguistic and speech motor processes on one another. This is the only study to date that has measured and reported longer WD in semantically blocked conditions.

Additionally, word production models fall into two distinct categories in regard to lexical access: discrete and cascaded. The discrete two-step models assume that speaking proceeds in a serial manner from semantic to phonological retrieval and that the two stages are largely disconnected from each other with no feedback from lower level to higher level processes (Levelt et al., 1999). In contrast, cascaded (Humphreys, Riddoch, & Quinlan, 1988) or interactive (Dell, 1986; Dell & O'Seaghdha, 1991; Harley, 1993) speech production models assume that all activated lexical-semantic representations affect phonological processing by spreading a proportional amount of activation to their corresponding phonological segments. Moreover, those models presume that the activation of the phonological word form occurs before the lexical selection takes place (cascaded processes), and that the information from the sub-lexical level affects the higher levels of processing.

However, the results from Chapters 2 and 3 indicate that the effects exhibited in speech motor execution are mediated by the cascading influences from the manipulations of linguistic variables and contrariwise. To clarify, in our study, the effect of semantic interference cascaded throughout the linguistic processes and influenced processes downstream from lexical access - including articulation and speech motor performance, where words that were semantically blocked required longer periods of time to be articulated. Perhaps the most striking finding of the present studies was that the manipulation of the articulatory complexity of words directly affected linguistic processing, where participants in this study demonstrated an increase in RT on complex words. That is, words that were considered articulatory complex required longer RT during naming. This result is indicative of the possibility that manipulations within the speech motor system may reshape the processing of the linguistic system. This distinct finding depicts the cascading relationship between linguistic and speech processes as the information from the sub-lexical levels (speech motor execution) impacting the higher levels of processing (linguistic processing and planning), providing additional evidence to support the cascaded models of lexical access (Caramazza, 1997; Costa et al., 2000; Cutting & Ferreira, 1999; Dell, 1986; Dell et al., 1997; Dell & O'Seaghdha, 1991).

Furthermore, an interaction between the linguistic and speech motor processes, as in blocking condition and articulatory complexity, was detected for PWA in this thesis. This interaction was exhibited in longer WD for complex words in the semantically blocked homogenous conditions when compared to WD for the same words in the heterogeneous conditions. This interaction was specifically detected for WD rather than RT, which is indicative that the interaction between linguistic and speech motor processes was occurring at the speech motor level rather than the lexical/semantic processing level. In addition, it is crucial to report that a further finding was identified, which determined that the PWA were the ones driving this interaction. This finding explicitly supports the notion that the interaction between the linguistic and speech motor processes becomes evident in individuals with impairments to their speech motor systems, such as aphasia. Moreover, this interaction further supports the previously discussed empirical studies that have illustrated significant effects of linguistic features on word articulation and articulatory features on linguistic processing (Smith & Goffman, 2004). Those considerations point to a complex interplay of linguistic and speech motor processes in the production of words for healthy adults as well as PWA.

To conclude, linguistic processing is generally argued to be at a higher level than speech motor processing, with a unidirectional flow from language to movement (Levelt et al., 1999). However, the results of our study demonstrate that manipulations of speech motor processes directly affect linguistic processing, validating the possibility that linguistic and speech motor processes may occur in parallel to one another and involve bidirectional interactive activation. The findings of the current study, specifically the interaction between speech motor and linguistic processes, is vital for both clinical and theoretical aspects in terms of word production in aphasia. Researchers and speech therapists must now consider the influence and interaction of speech motor processes on linguistic processes in order to acquire a holistic view of word production deficits in aphasia.

6.2.2 Phase II

Given that possible interactions between executive control and both linguistic and speech motor processes have potential implications for the success of the assessment and treatment of healthy ageing populations as well as adults with motor speech impairments, it is imperative that research focuses on the influence of all three processes on healthy ageing adults and people with aphasia (Kello et al., 2000; Lieberman, 2011; Strand & McNeil, 1996). Therefore, Phase II explored the relationship between linguistic, speech motor, and executive control processes in healthy younger and healthy older adults as well as in people with aphasia. Measures of executive control (inhibition, updating of working memory, and shifting) and linguistic (non-cyclical picture-naming task) were used to assess the relationship between the three targeted processes.

6.2.2.1 Findings in Chapter 4. Chapter 4 aimed to investigate how linguistic and speech motor processes in word production were influenced by updating, shifting, and inhibitory processes. In order to do this, data from the picture-naming task in Chapter 2 was used to measure the effect of semantic interference on linguistic processing (lexical access) whilst articulatory complexity was simultaneously manipulated as a measure of speech motor control. This chapter explored two research aims, the first of which was to determine the difference in the performance of executive control measures between healthy younger and healthy older adults. The significant differences in the performance of the healthy younger and the healthy older adults in our study validate previous research in this area where the HOA were less accurate, more error-prone, and required an increased amount of time to respond on all the executive control measures, compared to the HYA who responded faster and exhibited increased accuracy scores. Current and previous studies on executive control abilities have indicated that healthy older adults exhibit poorer inhibitory abilities and reduced memory spans (Hasher & Zacks, 1998, 1988; Hasher et al., 2007). Findings from this study add to the already well-established literature, providing further evidence to support the existence of an association between the healthy ageing process and impairments in executive functions, such as declines in inhibitory control (Aoki & fukuoka, 2010; Skurvydas & Krisciunas, 2013) and processing speed (Park et al., 2002; Salthouse, 1996; Salthouse, 2009).

The second aim was to determine if there is an interaction between the semantic interference effect on RT (linguistic processes), and WD (speech motor performance) and executive control processes (inhibition, updating, shifting) in healthy younger and older adults. Empirical evidence has demonstrated that, whilst speakers are attempting to produce a targeted item, the names of other semantically related items become activated. The increased activation of semantically related stimuli during the naming of items stimulates a semantic interference effect which manifests itself in the decreased accuracy of naming and longer reaction times (Belke et al., 2005; Schnur et al., 2006). Moreover, previous studies have reported evidence suggesting that executive control mechanisms are involved in the selection process during naming, with inhibition often argued to play an important role (de Zubicaracy et al., 2001, 2006; Guo et al., 2011; Roelofs, 2003; Shao et al., 2012). The findings from our study showed that inhibition, updating, and switching abilities interacted with both linguistic and speech motor processes. The HOA demonstrated an interaction between the effect of semantic interference on both linguistic and speech motor processes and inhibitory abilities. Additionally, the HOA displayed an interaction between updating abilities and the effect of semantic interference on linguistic processing.

6.2.2.2 Findings in Chapter 5. The comprehensive impairment profile for people with aphasia is important yet often overlooked, with emphasis being put on the language impairments, frequently disregarding the possible implications of the cognitive and speech motor impairments that commonly co-occur in people with aphasia (Cahana-Amitay & Albert, 2014; Villard & Kiran, 2014). Therefore, the purpose of Chapter 5 was to further our understanding of the possible interactions between linguistic, speech motor, and executive control processes in people with aphasia and age-matched healthy older adults.

The first aim of the study was to determine the difference in the performance of the people with aphasia and age-matched healthy controls on executive control processes. In line with previous studies, the PWA in this study performed significantly worse on all executive function tasks compared to the HC (de Bruijn et al., 2014; Wiener et al., 2004; Zakarias et al., 2013). The

PWA performed significantly slower than the HC adults on all executive control tasks, which is consistent with other studies on performance speed in Stroop trials (de Bruijn et al., 2014; Pompon et al., 2015; Scott & Wilshire, 2010; Wiener et al., 2004; Zakarias et al., 2013) and on tasks measuring updating abilities (Purdy, 2002). Overall, our findings demonstrate that the current group of PWA show a generalised cognitive slowing in executive control tasks.

The second aim of Chapter 5 was to determine if there is an interaction between the semantic interference effect on RT (linguistic processes), and WD (speech motor performance) and executive control processes (inhibition, updating, shifting) in people with aphasia and age-matched healthy controls. As mentioned previously, few studies (two known to date) have been conducted on people with aphasia to measure the possible associations between executive control processes, specifically inhibiting abilities, and lexical retrieval (Kuzmina & Weeks, 2017; Faroqi-Shah et al., 2016). In the current study, high percentage Stroop ratios - indicative of poor inhibitory abilities - were associated with word production measures for both the PWA and the HC. The PWA participants who demonstrated smaller Stroop ratios - better inhibitory abilities - were less affected by the semantic interference in the homogenous conditions and demonstrated better accuracy scores as well as shorter WD during picture-naming. These results demonstrate the complex relationship between linguistic (lexical access), speech motor (word durations), and executive control (inhibition) processes. This is a vital finding, as our study was the first of its kind that aimed to measure the interaction of all three processes: linguistic, speech motor, and executive functioning control in PWA. Additionally, the HC percentage Stroop ratios were correlated with accuracy scores in the picture-naming task.

Moreover, this study found no interactions between PWA and updating abilities; however, the HC participants who exhibited larger working memory capacities, evidenced by larger digit spans, also displayed a reduced semantic interference effect on naming accuracy and RT in the homogenous conditions as compared to the participants who demonstrated smaller working memories, correspondingly required longer RT and experienced a decrease in accuracy in the homogenous conditions. Crucially, no study to date has measured the association between shifting ability (task switching) and either or both linguistic and speech motor processes in PWA. However, in our study, in the tasks measuring switching ability, a single significant correlation was revealed between the effect of semantic interference on WD and the switch ratio on the Trail

Making Task for the PWA. The PWA who demonstrated an increase in switch costs (i.e., poorer switching abilities) were correspondingly affected to a greater degree by the effect of semantic interference on WD during picture-naming in the homogenous conditions.

Although executive control deficits are frequently identified in aphasia, this is not a universal finding. Some studies, ours included, that have measured executive control abilities in people with aphasia distinctly acknowledge that executive control impairments observed at the group level are not consistently demonstrated across the case series in people with aphasia (e.g., Murray, 2017; Seniów et al., 2009). Other studies have indicated that higher level cognition, including executive control, attention, and reasoning, is sometimes spared in individual cases of aphasia (Fedorenko & Varley, 2016; Varley, 2014). Therefore, it is unsurprising that the influence of the impairments in executive control in people with aphasia has not been systematically explored. Consequently, this thesis fulfils the gap in literature by investigating the influence of executive control processes on word production measures in participants with aphasia. Additionally, the results from Chapter 5 indicated that, although the group analyses pointed towards a general slowing for the PWA as compared to the HC — a likely consequence of acquired neurological damage— there were several individuals with aphasia who performed within normal limits in executive control tasks (see Table 5.4). For these individuals, despite the presence of language impairment, executive control abilities seem to have remained intact.

6.2.2.3 Significant contributions to literature of Phase II. Previous studies on word production and semantic interference have provided evidence for the importance of executive control mechanisms in the regulation of the activation of semantic competitors during naming in healthy younger and older adults (Crowther & Martin, 2014; Helm-Estabrooks, 2002; Shoa, Janse, Visser & Meyer, 2014; Shao et al., 2013; Scott & Wilshire, 2010; Hsu & Novick, 2016). However, to date, minimal studies have investigated the possible implications of the impairments in executive control and their influence on word production abilities in people with aphasia (Kuzmina & Weeks, 2017; Murray, 2012; Villard & Kiran, 2016). Those studies demonstrated associations between performance in executive control tasks measuring inhibition and the updating of working memory in specific components of language ability. The results from our studies corroborated results from those, providing evidence that executive control mechanisms play a vital role in lexical access/retrieval.

In our studies, in the tasks tapping into inhibition, the participants who demonstrated poorer inhibitory control on the executive control measures also required an increased amount of time to resolve the activated competing stimuli in the homogenous conditions during picture-naming. These results mirror results from previous studies that have measured the difference in the performance in executive control tasks and lexical access between healthy younger and healthy older adults (de Zubicaray, Wilson, McMahon, & Muthiah, 2001; Ren et al., 2014; Shao et al., 2015). Crucially, this is the first study to our knowledge that included measures of percentage Stroop ratio to assess inhibitory abilities as well as measures of accuracy, RT, and WD to assess linguistic and speech motor processes in healthy adults as well as PWA. The findings in our studies provided further evidence to support the existence of a link between lexical-retrieval and speech motor performance during word production and inhibitory abilities in PWA (Kuzmina and Weekes, 2016), HYA, and HOA (Sommers & Danielson, 1999; Shao, 2014), where performance on the Stroop task was significantly correlated with picture-naming measures, demonstrating the role of inhibition in resolving lexical-semantic competition during word retrieval. Importantly, high percentage Stroop ratios - indicative of poor inhibitory abilities - were associated with word production measures for both the PWA and the HOA. Namely, the PWA and healthy adults who demonstrated smaller Stroop ratios - indicative of better inhibitory abilities - were less affected by the semantic interference in the homogenous conditions and demonstrated shorter WD. This is a vital finding as our study was the first of its kind that aimed to measure the interaction of all three processes: linguistic, speech motor, and executive functioning control in PWA. These results demonstrate the complex relationship between linguistic (lexical access), speech motor (word durations), and executive control (inhibition) processes.

These findings corroborate the current literature, confirming that executive control processes play an important role in the success of impeccable communication through the resolution of the activated semantic competitors during lexical access/retrieval for both healthy adults and PWA. Specifically, our study substantiates the results of previous studies where inhibiting ability is associated to lexical-retrieval, suggesting that poor inhibitory ability leads to a failure in the inhibiting of the activated non-target competing lexical responses which further contributes to the impaired lexical-retrieval (Belke, 2008; Crowther & Martin, 2014; Kuzmina &

Weeks, 2017; Shoa et al., 2015). Moreover, there is growing empirical concern among aphasiologists that non-linguistic aspects of cognition, specifically executive control processes, may contribute to or exacerbate observed language deficits in individuals with brain injuries (Keil & Kaszniak, 2002).

In regard to the measurement of updating abilities, several studies have revealed associations between reduced working memory abilities and poor language comprehension in PWA (Caspari et al., 1998; Ivanova et al., 2015, 2017; Leff et al., 2009; Meteyard, Bruce, Edmundson, & Oakhill, 2015; Wright et al., 2007); however, no study has measured the association between updating abilities and word production in PWA. As the current study is the first of its kind measuring the association between updating abilities and word production in healthy adults as well as PWA, further research is needed to delve deeper into the possible role of updating abilities in word production.

To our knowledge, no study to date has measured the association between shifting ability (task switching) and either or both linguistic and speech motor processes in healthy younger adults, healthy older adults, and people with aphasia. However, in our studies, all three groups of participants (HYA, HOA, and PWA) demonstrated significant correlations between shifting abilities and measures of word production (effect of semantic interference on naming accuracy, RT and WD). Specifically, the HOA and PWA demonstrated multiple significant correlations, where the participants who demonstrated an increase in switch costs (i.e., poorer switching abilities) were correspondingly affected to a greater degree by the effect of semantic interference on naming accuracy, RT, and WD during picture-naming in the homogenous conditions. The participants who demonstrated smaller switch costs also demonstrated a smaller semantic interference effect on naming accuracy (higher accuracy), RT (shorter RT), and WD (shorter WD) in the homogenous conditions during picture-naming. This finding suggests that shifting ability could possibly contribute to lexical access through its involvement in reducing semantic interference during picture-naming. Additionally, results from this study indicated associations between switching ability and the effect of semantic interference on WD measures for both the PWA and the HOA, indicating the imbricate nature of all three processes (linguistic, speech motor, and executive control) during word production.

Previous studies in this area have suggested that cognitive abilities beyond language are important contributors to the rehabilitation and recovery of language in aphasia (Baldo et al., 2015; El Hachioui et al., 2014; Keil & Kaszniak, 2002; Mayer et al., 2017; Seniów et al., 2009). Many language therapy tasks require resources from multiple domains of cognition including attention, memory, executive control, and visuospatial processing (Vallila-Rohter, 2017). Therefore, solely focusing on language abilities during language rehabilitation fails to capture the bigger picture (see Cahana-Amitay & Albert, 2015). One possibility is that underlying non-linguistic cognitive deficits may contribute to observed language deficits and/or explain variability as to why some individuals respond well to therapy while others do not (Keil & Kaszniak, 2002; Vallila-Rohter, 2017).

Lastly, our findings highlight the importance of considering the broader word production impairment profile of PWA when interpreting language assessments, considering approaches to therapy, and understanding therapy outcomes. These results suggest that the degree to which lexical retrieval is disrupted in tasks such as the picture-naming task (Shao et al., 2013) is modulated by impairments in speech motor control and executive control processes. However, further research is needed to delineate the nature of the relationship between executive control and word production in PWA.

6.2.2.4 Significant contributions of Phase II to word production models. Previous theories of word production theories tend to assume fixed separation between lexical access, speech motor performance, and executive control. However, the results from Chapters 4 and 5 have provided vital evidence suggesting that linguistic, speech motor, and executive functioning processes are not independent, but rather synergetic processes that rely on each other for the impeccable execution of word production. These findings provide additional support for the inclusion of speech motor and executive functioning processes in or within linguistic processing levels of word production models (Levelt et al., 1999; Starreveld and La Heij, 1996). Additionally, as discussed above, the findings from Chapters 2 and 3 indicated that the cascade of spreading activation of semantic interference from lexical levels continues to speech motor levels, evidenced by longer WD on words in the homogenous conditions - these results are indicative of the association between lexical and speech motor processes. Moreover, Chapters 4 and 5 provided further evidence of the cascading information between cognitive (executive control), linguistic, and speech motor processes (Dell,1986; Dell & O'Seaghdha,1991; Harley,1993; Humphreys, Riddoch, & Quinlan,1988). To date, this thesis was the first of its kind that measured the influence of all three processes - linguistic, speech motor, and executive control - on healthy younger adults, healthy older adults, and people with aphasia, providing new evidence for the associations between all three processes.

6.3 Limitations and Future Directions

6.3.1 Cyclical Semantic Blocking Paradigm

The non-cyclical semantic blocking paradigm we have used in this thesis is unusual, with research in word production generally favouring the cyclical semantic blocking paradigm. As discussed in Chapter 1, there are a number of advantages to the method we have used; however, this method may not have been sufficient to elicit a robust semantic interference effect. A possible reason for the absence of the interactions between semantic blocking and articulatory complexity in Chapter 2 and the reduced correlations between the executive functioning tasks and word production measures in Chapters 4 and 5 is the lack of semantic interference.

Research utilising the blocked cyclical naming design have determined that the semantic interference effect emerges from cycle two onwards (Belke et al., 2005, see Belke & Steilow, 2013 for a review). As mentioned previously, the non-cyclical semantic blocking approach asks participants to name only once (once cycle) in the homogenous category and once in the heterogeneous category. However, in the standard version of the blocked-cyclical naming paradigm, participants are asked to name lists of objects compiled from several repetitions (cycles) of a small set of semantically related objects (homogeneous context) or unrelated objects (heterogeneous context) (see Figure 6.1).

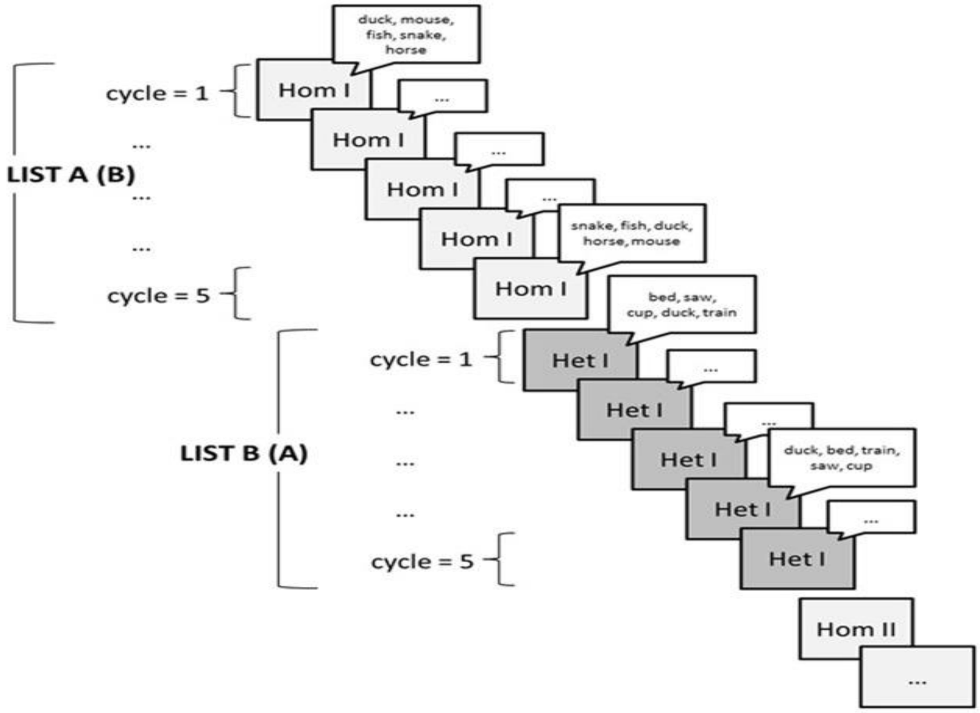


Figure 6.1 *Schematic representation of a standard blocked-cyclic naming paradigm from Belke et al. (2005).*

Belke et al. (2005) investigated the semantic interference effect and its build-up across cycles in a blocked cyclic-naming design with healthy undergraduate English monolingual students. Their blocked-cyclic naming design consisted of 32-line drawings, including four pictures from each of the four semantic categories (animals, tools, vehicle, and furniture) in eight presentation cycles. Homogenous and heterogenous items were presented in an alternate fashion (homogenous-heterogenous-homogenous-heterogenous). The results of their study found significant main effects of interference; that is, the RT during the naming of items in the homogenous sets were significantly slower than those in the heterogenous sets. Additionally, a significant interaction of context and cycle was found, where the semantic interference significantly affected the reaction times of naming from cycle two onward.

The implementation of the cyclical version of the semantic blocking naming paradigm in future studies could demonstrate the existence of the association between linguistic, speech motor, and executive functioning processes.

6.3.2 IPC Limitations

The use of IPC as a measure of phonetic complexity has been criticised by researchers (Howell et al., 2006). The IPC was developed for the assessment of early phonetic development, using factors of babbling and with the expectation that these have universal characteristics (MacNeilage & Davis, 1990). Some have argued that due to the apparent impact of phonetic difficulty on older adults (particularly on fluency) the IPC may need modifications in order to adapt the measure to this age group, as opposed to relying on the features of babbling (Howell et al., 2006). Criticism has also been directed at certain elements of the IPC that are not frequent in the British language. Despite this, the IPC has been used successfully in other studies focusing on the impact on phonetic complexity on adults (Bose et al., 2011). Ideally, alternative metric measures of complexity specific to healthy adults would have been employed; however, these have unfortunately not yet been formed. However, future studies could benefit from the implementation of acoustic and kinematic measures of speech motor performance.

6.3.3 Executive functions: Verbal vs Non-verbal

Task impurity refers to the notion that cognitive tasks seldom measure only the cognitive process they intend to measure. An executive control task will involve other cognitive processes, given that executive control abilities operate through other cognitive processes (Miyake, Emerson, et al., 2000). The approach of this thesis was to address this by measuring executive functioning ability through two different tasks in each domain to minimise the possible impact of language on executive functioning ability. However, there is a possibility that even for relatively low verbal tasks, such as the word colour Stroop and the Digit Span, there may be a need to recruit the language system. Therefore, the implementation of purely non-verbal executive functioning tasks in future studies would eliminate any possibility of the impaired language processes influencing the executive functioning abilities. This would then provide greater insights into the relationship between linguistic and executive control processes in healthy adults as well as in people with aphasia.

6.3.4 Lesion Location

Another limitation in this study is the lack of information of specific lesion location which is an important distinction between the fluent and non-fluent PWA. Previous literature has specified that those with non-fluent aphasia present with anterior lesion involvement, in comparison to the generally isolated posterior lesions associated with fluent aphasia (Naeser & Hayward, 1978). The inclusion of lesion location in future studies may have important implications for further exploring the overlap and divergence between the neurological networks that support language and executive control. With the recruitment of a larger sample of PWA with varying behavioural profiles and lesion sites, lesion analyses such as voxel-based lesion symptom mapping could be performed. In addition, recruitment of individuals with right-hemispheric lesions would further add to the conclusions from this thesis. For instance, the generalized slowing in executive control domains that PWA demonstrated in Chapter 5 is assumed to be a consequence of acquired neurological damage more generally, rather than specific to aphasia (Purdy, 2002). A comparison between individuals with right-hemispheric (non-language impaired) and left-hemispheric (PWA) lesions would allow for the investigation of task performance specific to language impairment rather than that of acquired neurological impairment more broadly.

6.4 Final Conclusion

This research systematically investigated the relationship between linguistic, speech motor, and executive control measures in people with aphasia and healthy older adults through the implementation of a linguistic task with a broad range of word production variables, distinctive analysis approaches, and a broad range of executive control tasks. The results of these studies provided greater insight to the influential nature of linguistic, speech motor, and executive control processes during word production in people with aphasia, to which there are some important implications for therapy and future research. Overarching these findings is the notion that the relationship amongst all three processes- linguistic, speech motor, and executive control- is complex, and challenging to study, but one that has intrigued historical researchers such as Jean Piaget and Lev Vygotsky through to the present day.

Appendices

Appendix 2.1 Demographic details of the HYA

Subject	Age	Sex	Years of education	Occupation	MMSE Score	DDK- / pʌ /	DDK- /tʌ /	DDK- /kʌ /	DDK- /pʌtəkə/
HYA 1	21	F	14	Student	27	5.14	6.43	5.57	4.36
HYA 2	21	F	14	Student	29	5.29	5.57	4.71	4.91
HYA 3	21	F	14	Student	30	6.14	7.00	6.71	5.64
HYA 4	26	M	18	Student	30	6.86	6.00	6.71	5.45
HYA 5	21	F	14	Student	30	5.57	6.43	5.14	6.91
HYA 6	21	M	14	Student	30	6.86	6.86	7.00	5.64
HYA 7	21	F	14	Student	30	7.14	5.86	6.57	6.18
HYA 8	32	F	20	Banking Manager	30	7.00	5.71	6.71	6.73
HYA 9	36	F	20	Carer	29	6.71	6.14	5.43	6.55
HYA 10	21	F	14	Student	29	6.86	5.71	6.43	6.73
HYA 11	21	F	14	Student	29	5.29	6.29	5.57	6.36
HYA 12	21	F	14	Student	30	6.00	6.00	5.14	7.09
HYA 13	24	F	14	Student	29	5.29	5.43	4.57	5.45
HYA 14	21	F	14	Student	29	5.71	6.86	6.57	5.64
HYA 15	21	F	14	Student	30	5.71	5.86	6.57	6.91
HYA 16	21	F	14	Student	29	6.86	5.71	5.14	7.09
HYA 17	21	F	14	Student	29	5.43	4.86	5.57	6.91
HYA 18	21	M	14	Student	30	6.71	5.86	5.29	7.09
HYA 19	21	F	14	Student	30	5.14	5.71	5.43	7.09
HYA 20	24	M	14	Student	29	6.14	6.00	6.14	6.00
HYA 21	21	F	14	Student	28	6.14	5.86	5.71	6.73
HYA 22	21	F	14	Student	29	6.00	6.14	6.43	6.55
HYA 23	28	F	20	Student	29	5.43	5.43	5.57	6.73
HYA 24	21	F	14	Student	30	5.86	5.29	4.43	6.36
HYA 25	21	F	14	Student	30	5.71	6.14	4.57	7.09
HYA 26	28	F	20	Student	29	5.57	5.71	6.57	6.55
HYA 27	21	F	14	Student	29	5.43	6.29	6.57	7.09
HYA 28	24	M	14	Student	30	5.86	6.00	6.14	6.18
HYA 29	21	F	14	Student	28	6.43	5.86	6.71	5.45
HYA 30	31	M	20	Student	30	6.86	6.86	5.43	5.64
Mean	23.13		15.13		29.33	6.04	6.00	5.84	6.30
Standard deviation	3.98		2.33		0.76	0.64	0.49	0.77	0.73

Appendix 2.2 Demographic details of the HOA

Subject	Age	Sex	Years of education	Occupation	MMSE Score	DDK- / pʌ /	DDK- /tʌ /	DDK- /kʌ /	DDK- /pʌtəkə/
HOA 1	73	F	18	Retired	29	5.29	5.29	5.57	5.82
HOA 2	57	M	18	Chartered secretary	30	7.29	8.29	6.57	6.00
HOA 3	73	M	18	Retired	30	6.43	6.43	5.57	5.27
HOA 4	91	M	14	Retired	27	6.57	7.43	6.43	4.91
HOA 5	74	F	14	Retired	28	6.43	6.29	6.14	4.73
HOA 6	75	F	18	Retired teacher	29	6.43	6.29	6.29	5.64
HOA 7	84	M	20	Retired	30	6.57	7.71	6.29	4.00
HOA 8	80	M	13	Retired civil servant	30	6.14	6.71	6.00	4.55
HOA 9	75	F	20	Retired sensory profiler	30	6.57	6.29	6.00	4.00
HOA 10	69	F	20	Retired	30	5.71	6.71	6.29	4.73
HOA 11	87	M	20	Retired	28	5.71	5.86	5.86	3.82
HOA 12	77	F	14	Retired medical receptionist	29	6.43	5.14	6.14	4.18
HOA 13	68	M	18	Retired gout officer	29	6.29	5.71	5.86	5.64
HOA 14	74	M	21	Retired	29	4.57	5.57	6.00	4.73
HOA 15	74	M	21	Retired hydrologist	28	6.14	5.43	5.71	5.09
HOA 16	67	M	14	Retired	25	6.57	5.14	5.43	4.36
HOA 17	61	F	18	Retired	30	6.57	5.86	6.43	4.91
HOA 18	80	M	18	Retired lecturer	30	5.43	5.29	5.86	5.27
HOA 19	69	F	15	Retired administrator	29	6.14	6.00	5.57	6.00
HOA 20	66	F	14	Retired programmer	30	6.14	5.71	5.43	4.36
HOA 21	75	F	14	Retired bar owner	28	5.86	5.57	6.29	5.45
HOA 22	75	M	13	Retired	29	6.86	5.29	5.14	4.55
HOA 23	69	F	14	Career advisor	28	5.14	5.86	5.57	5.45
HOA 24	88	F	13	Housewife	30	5.29	5.14	5.71	6.73
HOA 25	63	F	14	Receptionist	27	5.29	5.00	5.43	5.82
HOA 26	86	F	18	Retired teacher	30	5.86	4.71	5.71	7.45
HOA 27	58	F	13	Housewife	30	5.71	4.71	5.86	6.18
HOA 28	81	F	14	Retired	28	5.43	5.14	6.00	6.55
HOA 29	82	F	14	Retired	28	4.71	5.57	5.57	6.00
HOA 30	81	M	14	Retired	29	4.86	4.43	5.14	6.91
Mean	74.40		16.23		28.90	5.95	5.82	5.86	5.30
Standard deviation	8.71		2.79		1.21	0.67	0.89	0.38	0.93

Appendix 2.3 IPC scoring for all the Stimuli used in the Studies

	item	Category	Complexity	Phonetic transcription	IPC Total	1- Consonant place	2- consonant manner	3- vowel	4- Word Shape	5- word length	6- place variegation	7- contiguous consonants	8- cluster type
1	hippo	animals	simple	/ˈhɪpəʊ/	2	0	1	0	0	0	0	1	0
2	lion	animals	simple	/ˈlaɪən/	2	0	1	0	1	0	0	0	0
3	rabbit	animals	simple	/ˈræbɪt/	3	0	1	0	1	0	1	0	0
4	panda	Animals	simple	/ˈpændə/	1	0	0	0	0	0	0	1	0
5	bat	Animals	simple	/bæt/	2	0	0	0	1	0	1	0	0
6	walrus	Animals	complex	/ˈwɔːlrəs/	5	0	3	0	1	0	0	1	0
7	Dolphin	Animals	complex	/ˈdɒlfɪn/	5	0	2	0	1	0	0	1	1
8	Elephant	Animals	complex	/ˈelɪfənt/	5	0	2	0	1	1	0	1	0
9	skunk	Animals	complex	/skʌŋk/	8	3	1	0	1	0	0	2	1
10	zebra	Animals	complex	/ˈziːbrə/	4	0	2	0	0	0	0	1	1
11	Toe	body parts	simple	/təʊ/	0	0	0	0	0	0	0	0	0
12	thumb	body parts	simple	/θʌm/	3	0	1	0	1	0	1	0	0
13	elbow	body parts	simple	/ˈelbəʊ/	3	0	1	0	0	0	0	1	1
14	beard	body parts	simple	/bɪəd/	2	0	0	0	1	0	1	0	0
15	nose	body parts	simple	/nəʊz/	2	0	1	0	1	0	0	0	0
16	chest	body parts	complex	/ʧest/	4	0	2	0	1	0	0	1	0
17	finger	body parts	complex	/ˈfɪŋgə/	5	2	1	0	0	0	1	1	0
18	ankle	body parts	complex	/ˈæŋkl/	5	2	1	0	1	0	0	1	0
19	heel	body parts	complex	/hiːl/	4	0	2	0	1	0	1	0	0
20	lips	body parts	complex	/lɪps/	5	0	2	0	1	0	0	1	1
21	bed	furniture	simple	/bed/	2	0	0	0	1	0	1	0	0
22	chair	furniture	simple	/ʧeə/	2	0	1	1	0	0	0	0	0
23	lamp	furniture	simple	/læmp/	3	0	1	0	1	0	0	1	0
24	mirror	furniture	simple	/ˈmɪrə/	2	0	1	0	0	0	1	0	0
25	Window	furniture	simple	/ˈwɪndəʊ/	1	0	0	0	0	0	0	1	0
26	clock	furniture	complex	/klɒk/	6	2	1	0	1	0	0	1	1
27	shelf	furniture	complex	/ʃelf/	6	0	3	0	1	0	0	1	1
28	desk	furniture	complex	/desk/	5	1	1	0	1	0	0	1	1

29	stool	furniture	complex	/stuːl/	4	0	2	0	1	0	0	1	0
30	table	furniture	complex	/ˈteɪbl/	4	0	1	0	1	0	0	1	1
31	radio	musical instruments	simple	/ˈreɪdɪəʊ/	2	0	1	0	0	1	0	0	0
32	banjo	musical instruments	simple	/ˈbænʤəʊ/	3	0	1	0	0	0	1	1	0
33	drum	musical instruments	simple	/drʌm/	3	0	1	0	1	0	0	1	0
34	harp	musical instruments	simple	/hɑːp/	3	0	1	0	1	0	1	0	0
35	piano	musical instruments	simple	/pɪˈænəʊ/	1	0	0	0	0	1	0	0	0
36	Accordion	musical instruments	complex	/əˈkɔːdjən/	4	1	0	0	1	1	1	0	0
37	flute	musical instruments	complex	/fluːt/	5	0	2	0	1	0	0	1	1
38	Trumpet	musical instruments	complex	/ˈtrʌmpɪt/	4	0	1	0	1	0	0	2	0
39	violin	musical instruments	complex	/ˌvaɪəˈlɪn/	5	0	2	0	1	1	1	0	0
40	Whistle	musical instruments	complex	/ˈwɪsl/	4	0	2	0	1	0	0	1	0
41	belt	things to wear	simple	/belt/	3	0	1	0	1	0	0	1	0
42	hat	things to wear	simple	/hæt/	3	0	1	0	1	0	1	0	0
43	wig	things to wear	simple	/wɪg/	3	1	0	0	1	0	1	0	0
44	shoe	things to wear	simple	/ʃuː/	1	0	1	0	0	0	0	0	0
45	Tie	things to wear	simple	/taɪ/	0	0	0	0	0	0	0	0	0

46	dress	things to wear	complex	/dres/	4	0	2	0	1	0	0	1	0
47	jacket	things to wear	complex	/ˈdʒækɪt/	4	1	1	0	1	0	1	0	0
48	skirt	things to wear	complex	/skɜːt/	5	1	1	0	1	0	0	1	1
49	crown	things to wear	complex	/kraʊn/	5	1	1	0	1	0	0	1	1
50	glasses	things to wear	complex	/ˈglɑːsɪz/	7	1	3	0	1	0	0	1	1
51	hammer	tools	simple	/ˈhæmə/	2	0	1	0	0	0	1	0	0
52	nail	tools	simple	/neɪl/	2	0	1	0	1	0	0	0	0
53	ruler	tools	simple	/ˈruːlə/	2	0	2	0	0	0	0	0	0
54	saw	tools	simple	/sɔː/	1	0	1	0	0	0	0	0	0
55	tape	tools	simple	/teɪp/	2	0	0	0	1	0	1	0	0
56	axe	tools	complex	/æks/	5	1	1	0	1	0	0	1	1
57	drill	tools	complex	/drɪl/	4	0	2	0	1	0	0	1	0
58	lock	tools	complex	/lɒk/	4	1	1	0	1	0	1	0	0
59	pliers	tools	complex	/ˈplaɪəz/	5	0	2	0	1	0	0	1	1
60	shovel	tools	complex	/ˈʃʌvl/	5	0	3	0	1	0	1	0	0
61	ball	toys	simple	/bɔːl/	3	0	1	0	1	0	1	0	0
62	dice	toys	simple	/daɪs/	2	0	1	0	1	0	0	0	0
63	yoyo	toys	simple	/ˈjəʊjəʊ/	0	0	0	0	0	0	0	0	0
64	kite	toys	simple	/kaɪt/	3	1	0	0	1	0	1	0	0
65	tent	toys	simple	/tent/	2	0	0	0	1	0	0	1	0
66	carousel	toys	complex	/ˌkærʊˈsɛl/	8	1	3	1	1	1	1	0	0
67	puzzle	toys	complex	/ˈpʌzl/	4	0	2	0	1	0	0	1	0
68	robot	toys	complex	/ˈrəʊbɒt/	3	0	1	0	1	0	1	0	0
69	marbles	toys	complex	/ˈmɑːblz/	6	0	1	1	1	0	1	1	1
70	swing	toys	complex	/swɪŋ/	5	1	1	0	1	0	0	1	1
71	boat	transportation	simple	/bəʊt/	2	0	0	0	1	0	1	0	0
72	wagon	transportation	simple	/ˈwægən/	3	1	0	0	1	0	1	0	0
73	van	transportation	simple	/væn/	3	0	1	0	1	0	1	0	0
74	car	transportation	simple	/kɑː/	1	1	0	0	0	0	0	0	0
75	train	transportation	simple	/treɪn/	3	0	1	0	1	0	0	1	0
76	rocket	transportation	complex	/ˈrɒkɪt/	4	1	1	0	1	0	1	0	0

77	skis	transportation	complex	/skiːz/	6	1	2	0	1	0	0	1	1
78	bicycle	transportation	complex	/ˈbaɪsɪkl/	8	1	2	0	1	1	1	1	1
79	helicopter	transportation	complex	/ˈhelɪkɒptə/	7	1	2	0	0	1	1	1	1
80	saddle	transportation	complex	/ˈsædl/	4	0	2	0	1	0	0	1	0
81	kiwi	fuits and veg.	simple	/ˈkiːwi/	2	1	0	0	0	0	1	0	0
82	cherry	fuits and veg.	simple	/ˈʧɛri/	3	0	2	1	0	0	0	0	0
83	tomato	fuits and veg.	simple	/təˈmɑːtəʊ/	2	0	0	0	0	1	1	0	0
84	radish	fuits and veg.	simple	/ˈrædɪʃ/	3	0	2	0	1	0	0	0	0
85	lemon	fuits and veg.	simple	/ˈlemən/	3	0	1	0	1	0	1	0	0
86	Broccoli	fuits and veg.	complex	/ˈbrɒkəli/	7	1	2	0	0	1	1	1	1
87	apple	fuits and veg.	complex	/ˈæpl/	4	0	1	0	1	0	0	1	1
88	orange	fuits and veg.	complex	/ˈɒrɪnʤ/	4	0	2	0	1	0	0	1	0
89	pumpkin	fuits and veg.	complex	/ˈpʌmpkɪn/	4	1	0	0	1	0	0	1	1
90	grapes	fuits and veg.	complex	/greɪps/	8	1	2	0	1	0	0	2	2
91	robin	birds	simple	/ˈrɒbɪn/	3	0	1	0	1	0	1	0	0
92	duck	birds	simple	/dʌk/	3	1	0	0	1	0	1	0	0
93	gull	birds	simple	/gʌl/	1	1	0	0	0	0	0	0	0
94	owl	birds	simple	/aʊl/	2	0	1	0	1	0	0	0	0
95	turkey	birds	simple	/ˈtɜːkɪ/	2	1	0	0	0	0	1	0	0
96	eagle	birds	complex	/ˈiːgl/	5	1	1	0	1	0	0	1	1
97	ostrich	birds	complex	/ˈɒstrɪʧ/ˈ	5	0	3	0	1	0	0	1	0
98	penguin	birds	complex	/ˈpeŋgwɪn/	5	2	0	0	1	0	0	1	1
99	chicken	birds	complex	/ˈʧɪkɪn/	4	1	1	0	1	0	1	0	0
100	crow	birds	complex	/krəʊ/	4	1	1	0	0	0	0	1	1

Appendix 2.4 Lexical variables for the stimuli list

ITEM	CELEX total	CELEX written	CELEX spoken	log frequency	subject frequency	subject familiarity	AOA (bristol)	AOA (bird)	IMG (bristol)	IMG2 (bird)
hippo	0.73	0.78	0	0.24						
lion	16.98	17.35	12.31	1.25		511	244		626	
rabbit	10.78	11.39	3.08	1.07		523	206		611	
panda	0.84	0.9	0	0.26				452		600
bat	10.56	10.9	6.15	1.06	350	514		250	586	595
walrus	0.5	0.54	0	0.18		506			590	
dolphin	1.34	1.45	0	0.37				442		626
elephant	12.57	13.01	6.92	1.13		459	222		616	
skunk	0	0	0	0	310					
zebra	1.28	1.27	1.54	0.36				370		648
toe	9.61	10.06	3.85	1.03	463	578	194		620	
thumb	22.85	24.28	4.62	1.38	470	601	183		599	
elbow	15.64	16.57	3.85	1.22		564	237		602	
beard	22.18	23.19	9.23	1.37	380	480	260		631	
nose	73.02	76.27	31.54	1.87	463	584	206		605	
chest	43.46	46.14	9.23	1.65	450	509	302		551	
finger	49.39	52.53	9.23	1.7		621	178		648	
ankle	10.34	10.84	3.85	1.05		543	264		613	
heel	11.9	12.65	2.31	1.11	373	511	305		550	
lips	61.28	65.72	4.62	1.79						
bed	244.47	257.59	76.92	2.39	627	636	169		635	
chair	104.86	112.11	12.31	2.02	567	617			610	
lamp	21.28	22.65	3.85	1.35	517	578	283		575	
mirror	41.06	43.13	14.62	1.62		593	258		627	
window	132.51	139.7	40.77	2.13		621	231		602	
clock	35.59	37.17	15.38	1.56	593	636	210		640	
shelf	13.74	14.52	3.85	1.17	444	546	282		571	
desk	82.29	87.59	14.62	1.92	533	590	264		614	
stool	8.88	9.46	1.54	0.99	360	531	203		584	
table	203.63	214.58	63.85	2.31		599		185	582	
radio	83.97	74.52	204.62	1.93		644	317		613	
banjo	0.34	0.3	0.77	0.13						
drum	8.72	8.98	5.38	0.99	373	506		319	599	502
harp	2.4	2.53	0.77	0.53	270	430			621	
paino	0	0	0	0						
accordion	0.84	0.72	2.31	0.26		394			576	
flute	2.51	2.65	0.77	0.55	330	496			581	
trumpet	4.86	5.12	1.54	0.77		490			628	
violin	4.36	4.04	8.46	0.73		468			606	

whistle	9.66	10.18	3.08	1.03		505			574	
belt	21.17	22.11	9.23	1.35	443	577	268		585	
hat	53.07	55.18	26.15	1.73	493	580			562	
wig	6.7	7.17	0.77	0.89	323	518			587	
shoe	14.47	15.24	4.62	1.19	570	635	152		640	
tie	35.47	37.05	15.38	1.56	433	559			551	
dress	84.53	89.4	22.31	1.93	550	592	227	183	661	643
jacket	34.47	36.69	6.15	1.55		642	246		632	
skirt	20.89	21.93	7.69	1.34	443	551	258		573	
crown	24.47	25	17.69	1.41	297	447	245		645	
glasses	51.4	54.58	10.77	1.72						
hammer	12.57	12.71	10.77	1.13		472	274	297	668	552
nail	12.01	12.35	7.69	1.11	469	563	272		588	
ruler	7.65	7.89	4.62	0.94		571	311		543	
saw	387.88	401.02	220	2.59	553	552	269	336	531	507
tape	28.38	21.81	112.31	1.47	513	567	406		573	
axe	5.64	6.02	0.77	0.82	240	461	311		597	
drill	9.55	9.88	5.38	1.02	393	473		407	571	518
lock	21.28	22.23	9.23	1.35	563	588	328		532	
pliers	1.45	1.57	0	0.39		499			588	
shovel	4.13	4.22	3.08	0.71		528			538	
ball	92.96	97.35	36.92	1.97	530	575	150		622	
dice	2.18	2.35	0	0.5	343			531		351
yoyo	0	0	0	0						
kite	3.02	3.07	2.31	0.6	333	481			624	
tent	36.7	39.58	0	1.58	320	521	283		593	
carousel	1.23	1.33	0	0.35						
puzzle	7.77	8.19	2.31	0.94		486	320		510	
robot	3.74	3.98	0.77	0.68						
marbles	3.13	3.31	0.77	0.62						
swing	30.67	31.87	15.38	1.5	373	496	254	237	590	
boat	55.87	56.33	50	1.75	400	584		442	631	413
wagon	7.93	8.55	0	0.95		450	353		576	
van	54.25	57.05	18.46	1.74	423	542	267		572	
car	276.2	278.37	248.46	2.44	630	634	197		638	
train	78.99	75.3	126.15	1.9	393	548		443	593	406
rocket	8.1	8.25	6.15	0.96		525			612	
skis	2.96	2.17	13.08	0.6						
bicycle	17.93	18.67	8.46	1.28						
helicopte r	10.56	11.02	4.62	1.06						
saddle	8.83	9.52	0	0.99		436	344		578	
kiwi	0.61	0.66	0	0.21				544		510
cherry	5.92	6.27	1.54	0.84		514	317		582	
tomato	6.87	7.35	0.77	0.9		574			610	

radish	0.61	0.66	0	0.21						
lemon	13.02	14.04	0	1.15		518	280		632	
broccoli	0.89	0.96	0	0.28						
apple	17.6	18.67	3.85	1.27		598	211		637	
orange	29.5	31.27	6.92	1.48		567	203		626	
pumpkin	1.68	1.81	0	0.43				413		578
grapes	7.93	8.49	0.77	0.95						
robin	11.56	11.87	7.69	1.1		487	233		615	
duck	10.95	11.27	6.92	1.08	403	529	164		632	
gull	1.34	1.27	2.31	0.37	213					
owl	3.02	3.25	0	0.6	293	477	269		595	
turkey	13.46	13.92	7.69	1.16				540		408
eagle	7.21	7.65	1.54	0.91		462	313		625	
ostrich	1.62	1.75	0	0.42				427		574
penguin	3.85	3.61	6.92	0.69				392		620
chicken	30.45	32.17	8.46	1.5		544	250		619	
crow	3.97	4.22	0.77	0.7	337	490	308	279	578	591
Mean	30.93	32.05	16.72	1.09	425.49	537.80	255.79	374.45	599.20	535.67
SD	58.58	60.60	41.96	0.59	104.68	57.90	54.67	110.67	32.12	90.37

Appendix 2.5 List of Homogenous and Heterogenous Conditions

Homogenous category sets

Body Parts		Furniture		Toys		Tools	
Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
Toe	Chest	Bed	Clock	Ball	Carousel	Hammer	Axe
Thumb	Thumb	Chair	Shelf	Dice	Puzzle	Nail	Drill
Elbow	Elbow	Lamp	Desk	Yoyo	Robot	Ruler	Lock
Beard	Beard	Mirror	Stool	Kite	Marbles	Saw	Pliers
Nose	Nose	Window	Table	Tent	Swing	Tape	Shovel

Musical Instruments		Birds		Animals		Transportation	
Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
Radio	Accordion	Robin	Eagle	Hippo	Walrus	Boat	Rocket
Banjo	Flute	Duck	Ostrich	Lion	Dolphin	Wagon	Skis
Drum	Trumpet	Gull	Penguin	Rabbit	Elephant	Van	Bicycle
Harp	Violin	Owl	Chicken	Panda	Skunk	Car	Helicopter
Piano	Whistle	Turkey	Crow	Bat	Zebra	Train	Saddle

Fruit & Vegetables		Things to Wear	
Simple	Complex	Simple	Complex
Kiwi	Broccoli	Belt	Dress
Cherry	Apple	Hat	Jacket
Tomato	Orange	Wig	Skirt
Radish	Pumpkin	Shoe	Crown
Grapes	Turkey	Tie	Glasses

Heterogeneous Category sets

Het. 1	Het. 2	Het. 3	Het. 4

Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
Beard	Saddle	Tie	Bicycle	Tape	Skis	Van	Finger
Kiwi	Lock	Hippo	Puzzle	Drum	Skunk	Hammer	Violin
Duck	Accordion	Lamp	Axe	Shoe	Orange	Radish	Glasses
Rabbit	Marbles	Harp	Pumpkin	Chair	Chicken	Turkey	Walrus
Window	Jacket	Thumb	Crow	Lips	Carousel	Dice	Desk
Het. 5		Het. 6		Het. 7		Het. 8	
Simple	Complex	Simple	Complex	Simple	Complex	Simple	Complex
Car	Ankle	Toe	Rocket	Boat	Pliers	Elbow	Helicopter
Nail	Whistle	Saw	Apple	Nose	Flute	Piano	Drill
Belt	Eagle	Banjo	Penguin	Cherry	Skirt	Robin	Dress
Lemon	Dolphin	Wig	Zebra	Panda	Swing	Lion	Grapes
Yoyo	Stool	Bed	Tent	Gull	Clock	Mirror	Robot
Het. 9		Het. 10					
Simple	Complex	Simple	Complex				
Wagon	Chest	Train	Heel				
Owl	Shovel	Ruler	Elephant				
Ball	Trumpet	Hat	Table				
Tomato	Crown	Kite	Ostrich				
Bat	Shelf	Radio	Broccoli				

Appendix 2.6 List of the Randomized Sequence Structure for the Experiments

Sequence 1	**Sequence 2**	**Sequence 3**
Heterogeneous category 13	Transportation	Heterogeneous category15
Heterogeneous category 12	Heterogeneous category 16	Toys
Birds	Heterogeneous category 13	Heterogeneous category17
Heterogeneous category 19	Toys	Musical Instruments
Transportation	Musical Instruments	Fruits and Veg.
Fruits and veg.	Things to wear	Heterogeneous category18
Heterogeneous category 18	Heterogeneous category 17	Heterogeneous category11
Body parts	Furniture	Birds
Heterogeneous category 16	Heterogeneous category 19	Transportation
Things to wear	Tools	Heterogeneous category14
Furniture	Heterogeneous category 11	Heterogeneous category20
Musical Instruments	Heterogeneous category 20	Heterogeneous category19
Heterogeneous category 14	Body parts	Body parts
Animals	Heterogeneous category 14	Animals
Tools	Birds	Tools
Heterogeneous category 20	Heterogeneous category 12	Heterogeneous category13
Toys	Fruit and Veg.	Heterogeneous category16
Heterogeneous category 12	Animals	Things to wear
Heterogeneous category 15	Heterogeneous category 15	Heterogeneous category12
Heterogeneous category 17	Heterogeneous category 18	Furniture

Appendix 3.1 Individual data for the PWA and HC

Accuracy for the healthy controls						
	Het		**het Total (n=100)**	**homo**		**homo Total (n=100)**
	Complex (n=50)	**Simple (n=50)**		**Complex (n=50)**	**Simple (n=50)**	
HC 1	45	43	88	45	41	86
HC 2	47	47	94	47	47	94
HC 3	37	39	76	39	41	80
HC 5	47	48	95	48	48	96
HC 10	43	48	91	46	45	91
HC 12	43	47	90	43	44	87
HC 13	47	46	93	46	47	93
HC 14	46	47	93	44	46	90
HC 15	45	45	90	46	46	92
HC 16	44	46	90	47	48	95
HC 17	40	42	82	44	45	89
HC 18	44	45	89	46	46	92
HC 19	48	49	97	48	49	97
HC 20	43	48	91	42	50	92
HC 23	43	42	85	43	44	87
HC 25	48	46	94	48	47	95
HC 27	47	49	96	49	47	96
Mean	44.53	45.71	90.06	45.35	45.94	91.29
SD	2.94	2.78	54.42	2.60	2.461	4.36

Accuracy for the people with aphasia						
	Het		**het Total (n=100)**	**homo**		**homo Total (n=100)**
	Complex (n=50)	**Simple (n=50)**		**Complex (n=50)**	**Simple (n=50)**	
BH	46	47	93	48	44	92
CB	32	35	67	33	35	68
CB2	23	20	43	18	21	39
CD	32	34	66	32	35	67
CM	48	49	97	47	49	96
CW	23	20	43	16	17	33
DT	27	34	61	26	30	56
EM	44	44	88	44	45	89

HF	49	48	97	49	48	97
IB	35	43	78	31	41	72
NH	41	40	81	42	44	86
PS	14	13	27	23	22	45
PW	38	39	77	40	45	85
RB	28	36	64	29	35	64
RR	33	41	74	41	42	83
SA	44	42	86	44	44	88
WM	38	41	79	35	43	78
Mean	**35.00**	**36.82**	**135.67**	**35.12**	**37.65**	**137.56**
SD	**9.89**	**10.30**	**19.83**	**10.48**	**9.85**	**19.93**

Average reaction times for the healthy controls						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
HC 1	715.27	706.74	711.10	770.80	709.61	741.63
HC 2	825.15	798.57	811.86	815.34	810.02	812.68
HC 3	752.51	741.56	746.89	876.46	853.83	864.86
HC 5	763.51	734.31	748.76	821.21	767.38	794.29
HC 10	744.86	678.92	710.08	802.07	720.27	761.62
HC 12	642.44	629.04	635.44	721.30	627.55	673.89
HC 13	725.45	736.72	731.02	804.87	755.57	779.96
HC 14	740.96	744.45	742.72	746.73	757.65	752.31
HC 15	911.76	832.82	872.29	936.24	875.00	905.62
HC 16	650.89	628.07	639.22	669.36	693.44	681.53
HC 17	779.65	765.26	772.28	1124.25	784.67	952.55
HC 18	838.75	844.31	841.56	837.83	853.24	845.53
HC 19	765.85	740.65	753.12	878.46	853.20	865.70
HC 20	692.09	722.38	708.07	811.12	780.38	794.41
HC 23	760.72	772.40	766.49	858.30	824.84	841.38
HC 25	715.50	649.76	683.33	748.69	670.87	710.19
HC 27	801.57	711.84	755.77	814.98	747.96	782.17
Mean	**755.01**	**730.76**	**742.73**	**824.83**	**769.90**	**797.19**
SD	**66.75**	**62.46**	**62.38**	**99.97**	**70.62**	**76.14**

Average reaction times for the people with aphasia						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	

BH	1046.70	1029.11	1037.81	1277.33	1119.59	1201.89
CB	1495.06	1227.46	1355.27	1761.30	1606.60	1681.68
CB2	2104.13	1767.40	1947.51	1871.53	1928.71	1903.13
CD	2735.66	1768.00	2237.17	3303.78	1782.23	2508.94
CM	1257.54	1151.59	1204.02	1663.60	1219.27	1436.80
CW	2008.87	1865.80	1942.33	2708.75	2323.53	2510.30
DT	1171.22	1056.50	1107.28	1327.88	1248.43	1285.32
EM	959.23	910.27	934.75	1310.64	1241.02	1275.44
HF	830.53	831.77	831.14	880.51	852.85	866.82
IB	1424.11	1248.21	1327.14	1601.58	1559.76	1577.76
NH	1178.88	1130.20	1154.84	1372.79	1356.09	1364.24
PS	1276.64	1231.50	1255.81	2255.39	2166.41	2211.89
PW	1349.58	1234.56	1291.32	1741.98	1717.60	1729.07
RB	1673.68	1525.92	1590.56	2021.55	1780.66	1889.81
RR	1866.00	1182.34	1487.22	2733.00	1843.88	2283.08
SA	1204.36	1143.80	1175.15	1510.95	1255.66	1383.31
WM	2328.03	2022.90	2169.67	2662.91	2403.42	2519.86
Mean	**1077.91**	**1028.06**	**1053.08**	**1066.84**	**1025.90**	**1046.70**
SD	**266.64**	**255.77**	**258.85**	**291.566**	**277.66**	**283.377**

Average of word duration for the healthy controls						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
HC 1	391.51	323.77	358.41	404.78	336.95	372.44
HC 2	510.28	430.57	470.43	510.96	452.30	481.63
HC 3	568.27	494.77	530.55	605.51	546.27	575.15
HC 5	539.00	475.94	507.14	559.08	479.56	519.32
HC 10	587.28	503.75	543.22	607.50	509.76	559.16
HC 12	410.74	355.70	382.00	433.49	365.36	399.03
HC 13	475.38	440.26	458.01	523.35	465.57	494.15
HC 14	490.57	419.85	454.83	505.16	446.39	475.12
HC 15	559.73	486.64	523.19	564.22	489.65	526.93
HC 16	475.23	406.17	439.93	481.47	430.75	455.84
HC 17	585.35	507.40	545.43	626.09	537.78	581.44
HC 18	560.50	493.16	526.45	564.24	523.89	544.07
HC 19	493.52	472.08	482.69	577.31	536.90	556.90
HC 20	419.88	388.60	403.38	447.36	422.88	434.05
HC 23	498.56	442.74	470.98	528.84	470.75	499.46

HC 25	535.50	467.30	502.13	539.85	474.98	507.76
HC 27	530.06	494.55	511.94	564.31	503.00	534.29
Mean	**506.94**	**447.08**	**476.62**	**532.37**	**470.61**	**501.29**
SD	**59.73**	**54.00**	**55.97**	**62.64**	**58.24**	**59.70**

Average of word duration for the people with aphasia						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
BH	541.30	486.11	513.41	582.17	548.18	565.91
CB	601.59	476.00	535.99	772.76	487.29	625.82
CB2	645.91	531.15	592.53	677.72	548.10	607.92
CD	606.53	434.56	517.94	676.78	471.71	569.66
CM	664.19	549.71	606.36	746.38	558.02	650.24
CW	583.91	499.35	544.58	629.63	546.06	586.58
DT	584.44	453.32	511.36	759.08	523.13	632.68
EM	671.16	598.52	634.84	787.39	673.69	729.90
HF	617.65	531.71	575.12	625.39	522.33	574.39
IB	533.31	453.07	489.08	606.10	455.07	520.10
NH	546.34	455.38	501.42	613.93	497.66	554.44
PS	707.29	531.15	622.48	796.87	604.18	702.67
PW	663.89	505.33	583.58	661.73	532.56	593.34
RB	555.43	405.17	470.91	569.34	451.83	505.08
RR	589.76	426.80	499.47	685.20	496.17	589.54
SA	702.61	545.52	625.90	750.73	593.91	672.32
WM	1024.61	735.46	874.54	1116.49	782.49	932.36
Mean	**639.27**	**508.88**	**572.42**	**708.30**	**548.67**	**625.78**
SD	**99.84**	**66.39**	**81.26**	**109.43**	**74.42**	**90.83**

Average reaction times for the healthy younger adults- Repetition						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
HC 1	793.7	760.8	777.3	785.5	760.0	772.7
HC 2	1107.5	1090.0	1098.3	1138.8	1122.7	1131.1
HC 3	881.6	819.7	850.0	911.5	851.3	881.1
HC 4	721.3	695.5	708.4	772.5	737.9	755.2
HC 5	926.6	909.0	917.9	926.3	895.8	911.0
HC 6	688.5	671.5	680.0	704.7	683.0	693.9

HC 7	695.1	682.0	688.6	693.1	682.3	687.8
HC 8	790.9	740.2	765.8	827.9	782.8	805.3
HC 9	939.3	883.4	911.9	914.6	860.5	887.0
HC 10	686.7	672.9	679.8	700.9	692.9	696.9
HC 11	918.9	875.4	896.7	921.2	901.6	911.5
HC 12	683.0	673.7	678.4	693.0	692.0	692.5
HC 13	782.9	746.2	764.7	797.0	755.8	776.6
HC 14	693.2	676.1	684.6	682.6	664.6	673.6
HC 15	513.2	501.9	507.6	531.5	487.7	509.6
HC 16	890.0	861.1	875.6	856.1	827.5	841.9
HC 17	744.0	710.6	727.3	750.9	732.8	741.9
HC 18	881.0	860.8	871.0	875.6	842.7	859.1
HC 19	724.5	678.1	701.8	685.7	712.7	699.2
HC 20	665.8	660.6	663.2	655.1	649.1	652.1
HC 21	758.1	728.6	743.4	722.0	721.6	721.8
HC 22	818.7	798.6	808.7	815.2	783.1	799.2
HC 23	828.9	762.0	795.5	836.8	784.3	810.5
HC 24	556.5	513.4	535.0	532.9	521.9	527.4
HC 25	695.1	682.0	688.6	693.1	682.3	687.8
HC 26	785.3	747.8	766.4	777.7	735.8	756.8
HC 27	882.3	860.4	871.4	891.7	877.1	884.5
HC 28	872.0	852.6	862.3	891.9	893.3	892.6
HC 29	791.4	770.8	781.1	789.4	777.2	783.3
HC 30	934.0	874.5	904.5	886.5	882.1	884.3
Mean	788.3	758.7	773.5	788.7	766.5	777.6
SD	123.4	119.0	120.9	125.5	122.0	123.4

Average word durations for the healthy younger adults- Repetition						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
HC 1	575.6	506.5	541.1	581.1	503.4	542.6
HC 2	627.4	555.9	591.7	632.2	560.7	596.1
HC 3	562.3	502.7	532.5	553.4	492.0	522.7
HC 4	544.9	487.1	516.0	560.1	494.2	527.1
HC 5	529.4	472.7	501.1	530.5	472.8	501.6
HC 6	422.2	361.4	391.8	453.6	377.6	415.6
HC 7	465.4	395.3	430.4	473.3	406.5	439.9
HC 8	525.2	467.8	496.5	531.7	484.1	507.9

HC 9	540.5	476.1	508.3	532.5	463.1	497.8
HC 10	652.4	591.0	621.1	659.2	589.7	624.4
HC 11	666.0	589.7	629.1	665.0	569.3	617.1
HC 12	573.2	526.7	549.9	574.2	519.7	547.0
HC 13	595.4	511.6	553.5	563.7	509.8	537.0
HC 14	471.1	441.7	456.4	459.3	415.3	437.3
HC 15	426.7	381.3	404.0	420.8	378.8	399.8
HC 16	556.1	495.7	525.9	550.3	496.0	523.2
HC 17	522.2	477.5	499.9	528.7	471.1	499.9
HC 18	516.4	436.1	476.3	525.0	430.3	477.7
HC 19	548.9	487.0	518.0	555.8	474.5	515.2
HC 20	482.2	433.2	457.7	479.5	409.0	444.3
HC 21	497.6	449.1	473.4	499.7	447.1	473.7
HC 22	570.2	498.6	534.7	596.7	491.9	544.8
HC 23	561.4	502.6	532.3	542.7	493.0	517.9
HC 24	448.6	421.6	435.1	451.2	406.7	429.0
HC 25	465.4	395.3	430.4	473.3	406.5	439.9
HC 26	516.1	450.9	483.5	506.3	471.0	488.7
HC 27	600.6	515.7	558.1	601.1	525.7	563.8
HC 28	415.5	416.4	416.0	417.5	386.3	401.9
HC 29	554.3	475.4	514.8	556.3	488.2	522.2
HC 30	510.1	449.6	479.8	506.6	451.6	479.1
Mean	**755.01**	**730.76**	**742.73**	**824.83**	**769.90**	**797.19**
SD	**66.75**	**62.46**	**62.38**	**99.97**	**70.62**	**76.14**

Average reaction times for the healthy older adults- Repetition						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
HOA 1	834.6	831.7	833.2	821.5	832.0	826.7
HOA 2	793.1	817.9	805.5	833.1	790.5	811.8
HOA 3	702.0	683.3	692.7	676.2	663.3	669.8
HOA 4	890.8	979.5	935.7	997.1	994.8	996.0
HOA 5	888.4	861.2	874.7	923.7	885.7	904.7
HOA 6	734.5	735.3	734.9	714.7	730.1	722.1
HOA 7	729.0	725.5	727.3	719.2	732.1	725.6
HOA 8	765.9	781.9	773.8	799.4	765.6	782.7
HOA 9	868.3	890.2	879.3	912.4	870.8	892.2
HOA 10	772.1	718.5	745.0	742.4	733.1	737.7

HOA 11	840.3	840.8	840.5	845.4	866.5	855.3
HOA 12	870.2	882.7	876.4	894.9	897.5	896.2
HOA 13	795.0	783.2	789.1	800.8	785.8	793.4
HOA 14	762.9	757.1	760.0	743.3	791.6	767.2
HOA 15	934.4	983.0	958.4	1052.4	1039.3	1046.1
HOA 16	768.9	778.3	773.6	762.2	766.7	764.4
HOA 17	841.0	831.9	836.4	878.7	859.8	869.2
HOA 18	927.0	929.7	928.4	958.8	942.6	950.7
HOA 19	972.6	1030.6	1000.6	1033.9	1040.0	1036.9
HOA 20	809.7	789.0	799.3	811.5	793.2	802.3
HOA 21	819.9	815.4	817.6	831.3	813.4	822.3
HOA 22	900.1	864.1	882.3	887.8	964.5	925.7
HOA 23	863.2	800.8	832.0	844.2	813.6	828.9
HOA 24	850.3	901.0	873.7	817.2	862.5	838.8
HOA 25	869.7	851.0	860.4	867.4	830.2	848.8
HOA 26	883.4	961.1	924.6	996.3	963.2	979.3
HOA 27	860.0	831.4	845.7	862.9	830.6	847.1
HOA 28	921.9	916.1	919.1	905.0	917.9	911.3
HOA 29	829.2	842.2	835.6	818.2	846.7	832.0
HOA 30	873.6	894.1	884.0	940.8	971.9	957.3
Mean	839.1	843.6	841.3	856.4	853.2	854.8
SD	65.7	83.6	73.2	94.7	94.7	93.6

Average word durations for the healthy older adults- Repetition						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
HOA 1	390.9	366.3	378.8	407.9	390.1	399.1
HOA 2	579.6	511.3	545.4	590.4	519.5	554.9
HOA 3	555.7	488.3	522.0	577.9	494.6	536.7
HOA 4	728.1	648.5	690.0	775.0	663.5	719.8
HOA 5	616.7	520.2	568.0	607.4	529.9	568.7
HOA 6	562.1	486.1	524.5	577.7	490.4	535.4
HOA 7	479.1	448.6	464.4	477.8	439.1	458.6
HOA 8	572.7	468.1	520.4	540.3	480.5	510.4
HOA 9	619.5	551.2	585.4	637.5	538.3	587.9
HOA 10	631.5	514.2	572.8	629.2	533.0	581.1
HOA 11	513.9	460.9	487.7	513.0	477.3	496.0
HOA 12	598.7	551.0	574.9	601.7	549.5	575.6
HOA 13	610.8	555.2	583.3	622.6	530.0	576.3

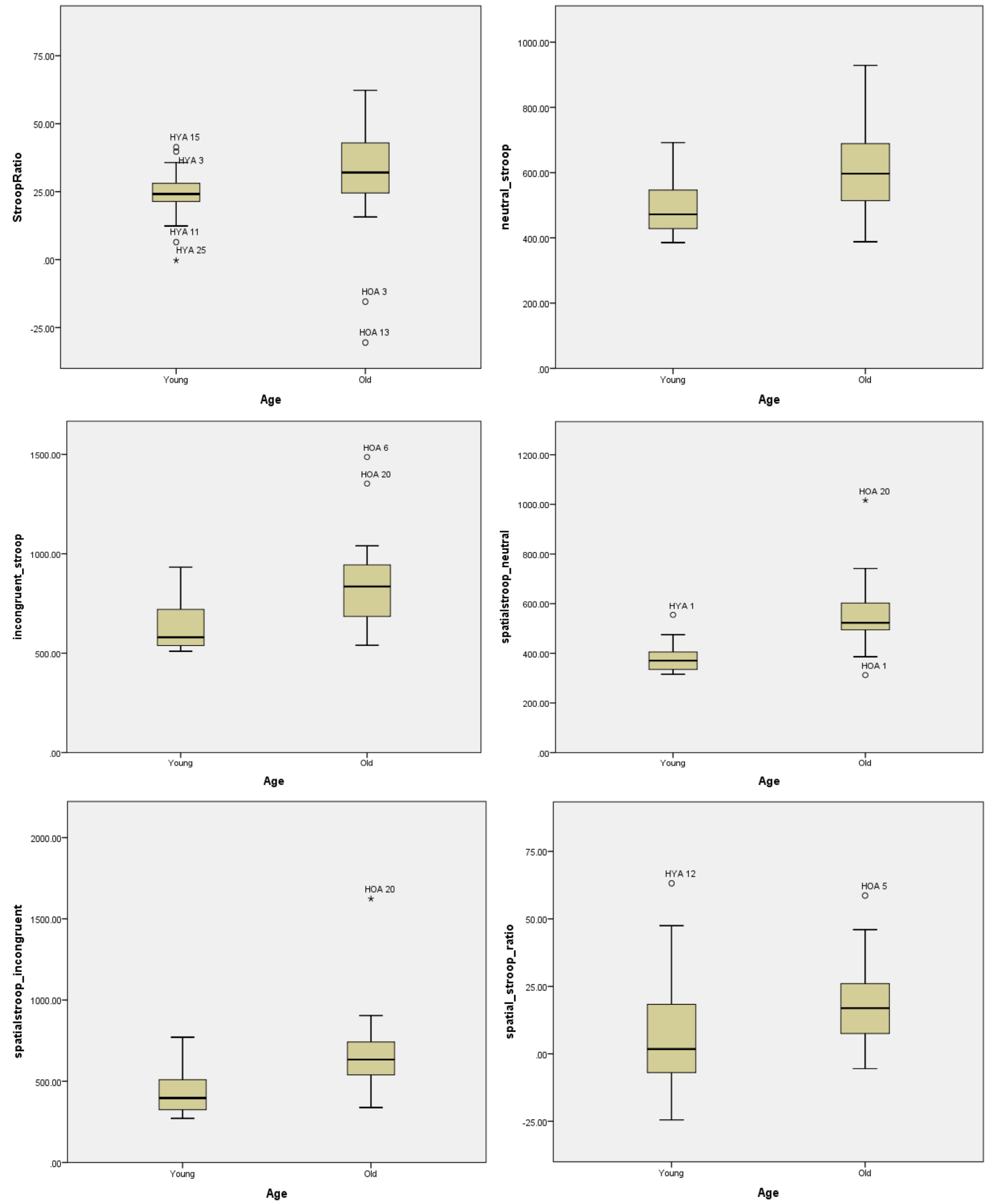
HOA 14	548.0	469.5	509.2	548.8	488.0	518.7
HOA 15	623.1	540.0	582.5	614.6	556.7	586.6
HOA 16	531.7	480.2	506.0	546.9	495.8	521.6
HOA 17	599.6	519.1	559.4	600.0	522.9	561.5
HOA 18	588.9	522.2	555.2	591.1	495.7	542.9
HOA 19	620.8	547.0	583.9	630.3	545.8	587.6
HOA 20	508.6	459.6	484.1	520.4	462.5	491.5
HOA 21	568.1	500.7	534.1	573.4	507.5	540.2
HOA 22	615.1	544.5	579.8	628.2	570.8	599.5
HOA 23	519.0	445.2	482.1	526.5	452.6	489.6
HOA 24	525.4	452.2	490.8	531.5	461.4	497.6
HOA 25	585.2	508.4	547.2	579.4	519.6	549.5
HOA 26	611.7	554.9	584.1	619.8	546.7	581.4
HOA 27	570.6	487.9	529.3	562.3	498.9	530.6
HOA 28	648.1	549.0	599.1	648.4	557.0	604.1
HOA 29	511.3	442.2	476.7	501.9	443.2	472.6
HOA 30	559.4	502.5	531.6	560.3	517.4	538.2
Mean	573.1	503.2	538.4	578.1	509.3	543.8
SD	61.6	51.9	56.2	65.2	50.4	57.3

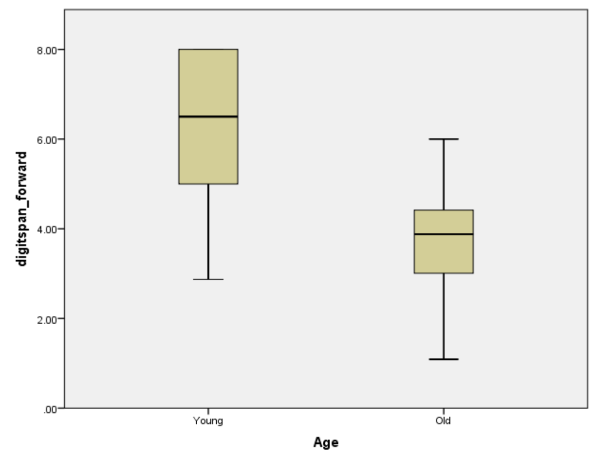
Average reaction times for the people with aphasia - repetition						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**simple**	
BH	924.59	824.24	873.91	982.64	891.57	939.00
CB	946.52	898.47	922.74	928.08	869.61	899.14
CB2	1007.96	948.89	978.42	1026.48	908.09	967.93
CD	846.84	802.16	824.50	845.00	809.32	827.16
CM	1367.22	1146.54	1256.88	1188.86	1124.96	1156.91
CW	1164.61	1106.10	1136.03	1066.89	1130.70	1097.75
DT	898.54	896.88	897.71	845.34	854.04	849.69
EM	1031.89	1000.74	1017.26	1061.80	1052.89	1057.64
HF	872.82	1007.63	939.53	858.22	884.91	871.00
IB	925.14	886.48	905.81	888.10	857.36	872.73
NH	994.74	947.76	971.25	905.50	936.29	920.58
PS	964.15	973.77	968.96	1003.92	956.17	980.54
PW	974.39	868.90	921.11	973.68	868.69	922.26

RB	1039.88	985.20	1012.54	1018.76	1001.48	1010.12
RR	1247.59	1240.34	1243.93	1259.34	1149.06	1204.76
SA	1135.18	1015.63	1076.01	1181.40	1104.02	1143.10
WM	1963.06	1917.30	1940.18	2092.70	2011.56	2052.13
Mean	1076.77	1027.47	1052.16	1066.28	1024.16	1045.44
SD	266.64	255.77	258.85	291.57	277.66	283.38

Average word durations for the people with aphasia - Repetition						
	het		**het Total**	**homo**		**homo Total**
	complex	**simple**		**complex**	**Simple**	
BH	508.27	486.82	497.43	518.46	481.96	500.97
CB	631.42	523.76	578.13	636.12	535.86	586.49
CB2	687.67	603.28	645.48	670.80	602.04	636.80
CD	565.40	495.02	530.21	568.76	508.86	538.81
CM	632.94	543.92	588.43	672.04	562.94	617.49
CW	579.57	591.38	585.34	594.02	530.41	563.26
DT	606.36	529.46	567.91	609.40	512.88	561.14
EM	665.80	589.06	629.76	671.07	604.11	639.77
HF	572.06	503.08	537.93	553.80	512.11	533.84
IB	468.88	410.96	439.92	460.74	396.08	428.41
NH	589.28	508.74	549.01	568.00	485.96	527.82
PS	749.02	629.00	689.01	771.37	599.53	687.24
PW	753.22	625.02	688.47	759.84	639.40	700.85
RB	563.32	484.54	523.93	551.06	494.30	522.68
RR	582.04	474.80	527.88	566.36	490.82	528.97
SA	797.20	613.27	706.16	799.28	687.22	743.82
WM	824.94	638.36	731.65	865.32	648.06	756.69
Mean	633.96	544.15	589.21	637.44	546.62	592.65
SD	99.83	66.39	81.25	109.42	74.42	90.82

Appendix 4.1 Boxplots for the executive function tasks to indicate outliers

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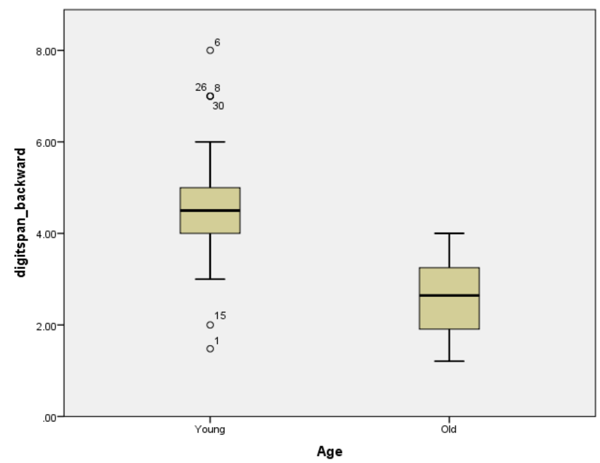
4.00
2.00
.00
Young
Old
Age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2.00
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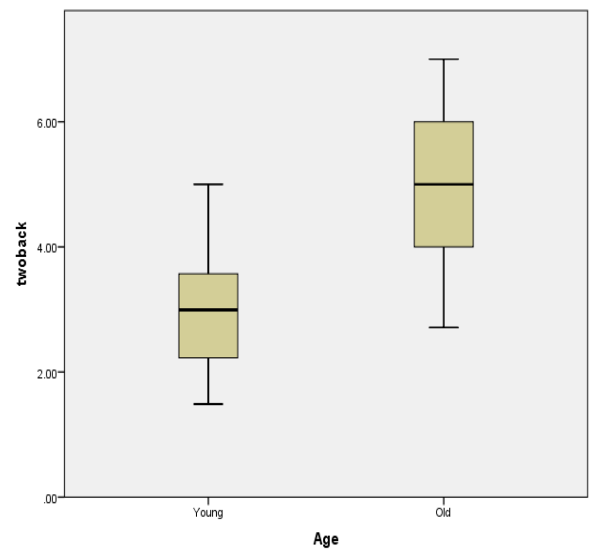
30
15
1
Young
Old
Age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4.00
2.00
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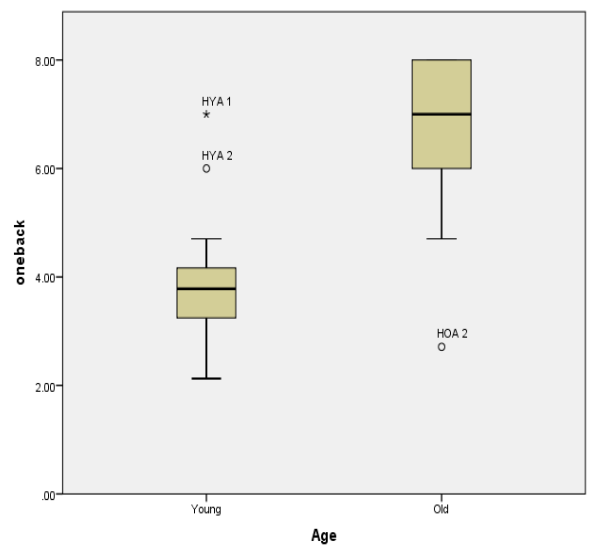
Young
Old
Age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4.00
2.00
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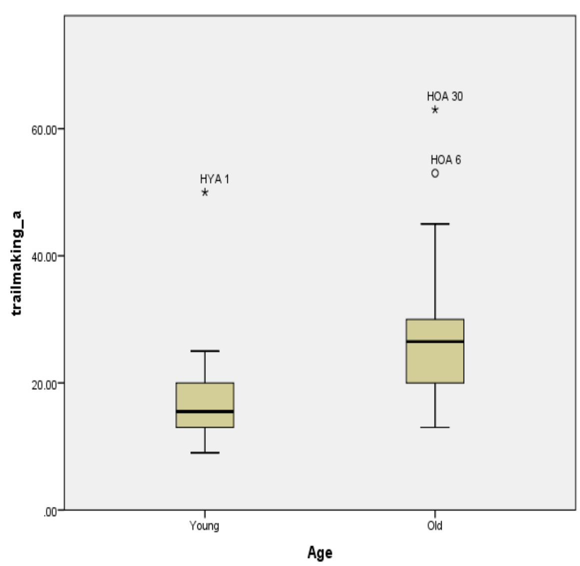
HYA 2
HOA 2
Young
Old
Age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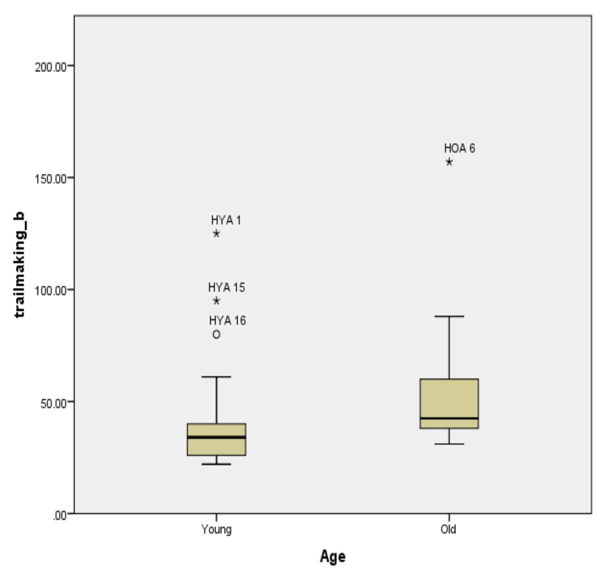
HOA 6
Young
Old
Age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50.00
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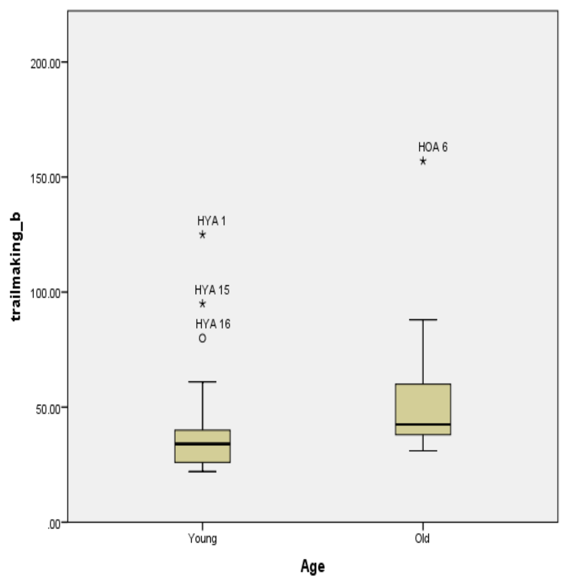
HYA 15
HYA 16
HOA 6
Young
Old
Age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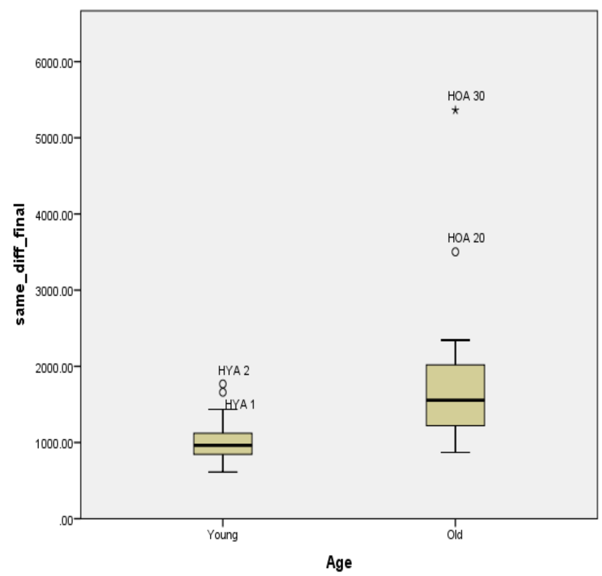
HYA 15
HYA 16
HOA 6
Young
Old
Age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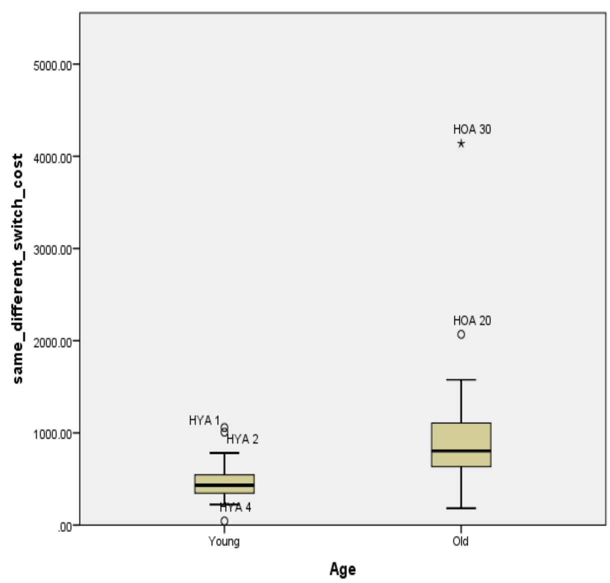
HOA 20
HYA 2
HYA 1
Young
Old
Age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4000.00
3000.00
2000.00
1000.00
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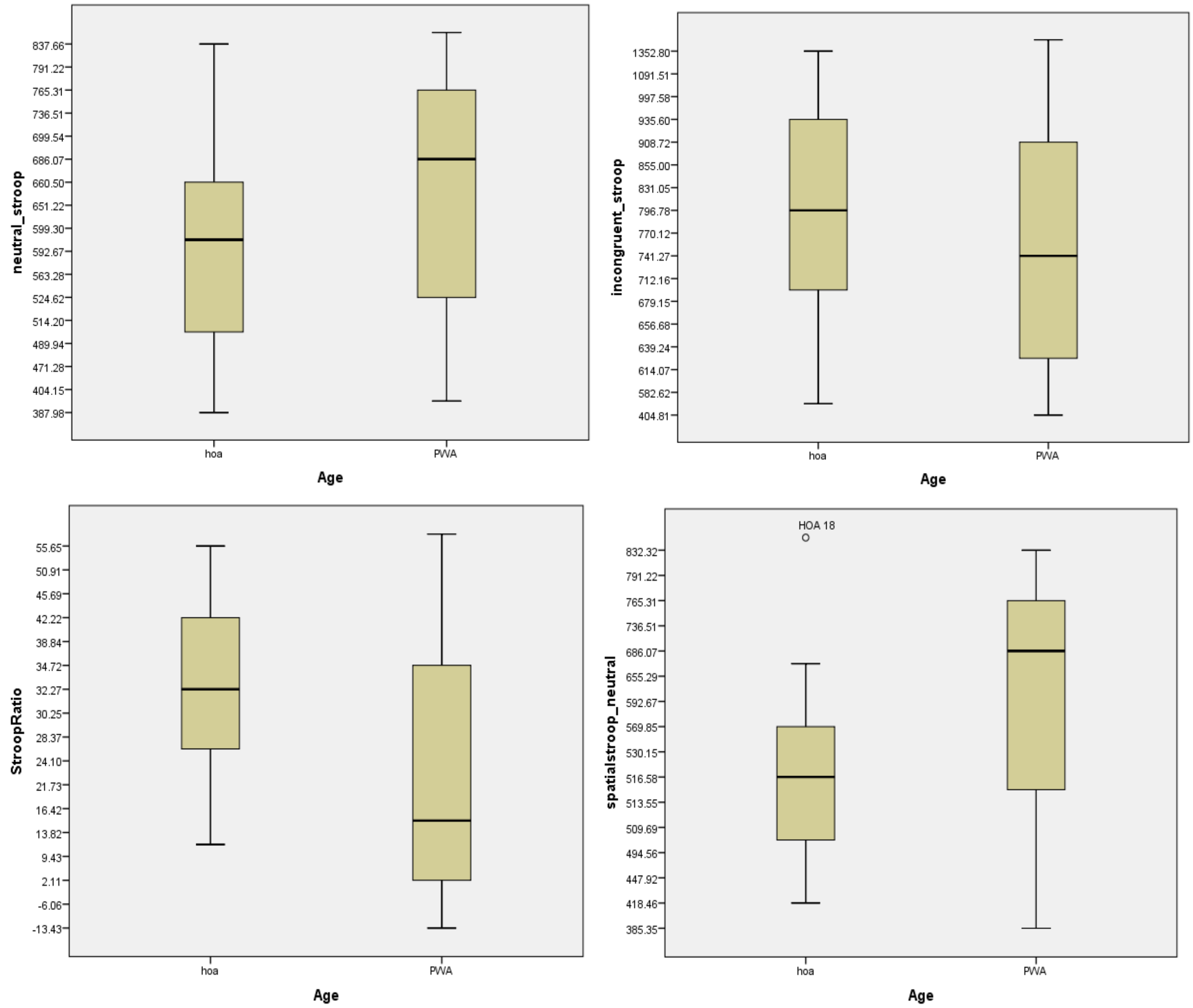
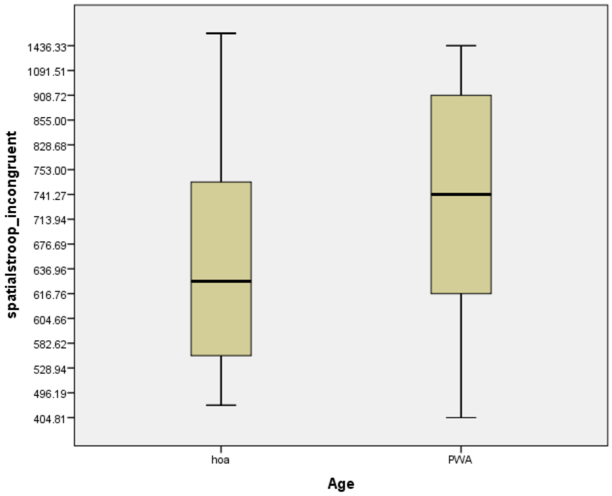
HOA 30
HOA 20
HYA 1
HYA 2
HYA 4
Young
Old
Age

Appendix 5.1 Boxplots for the executive function tasks to indicate outliers

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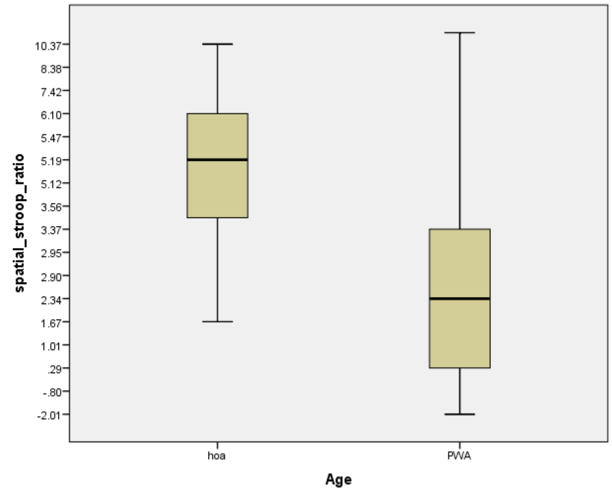
616.76
604.66
582.62
528.94
496.19
404.81
hoa
PWA
Age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.29
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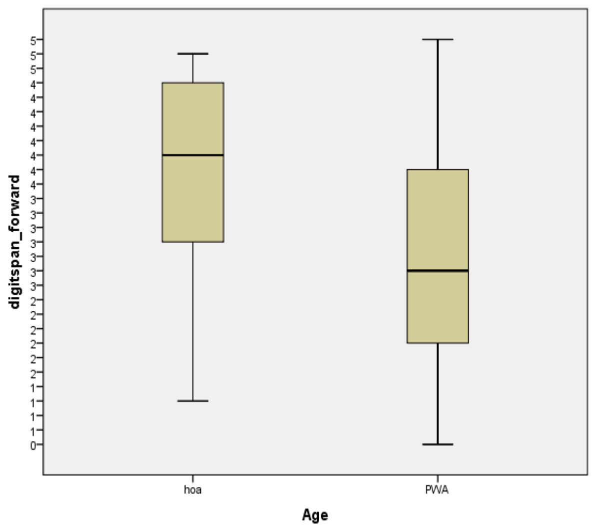
hoa
PWA
Age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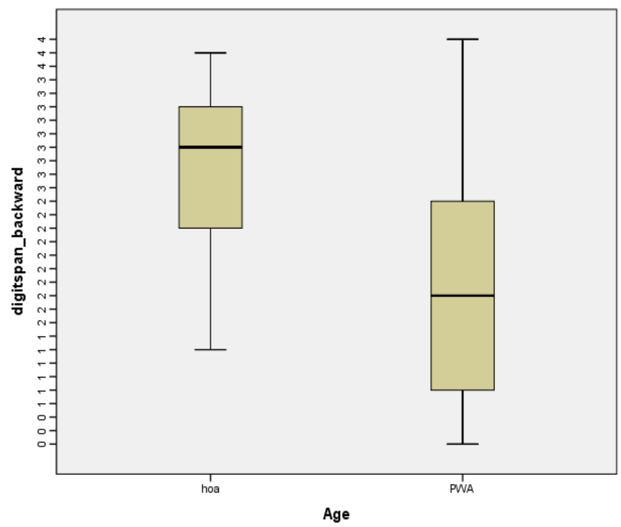
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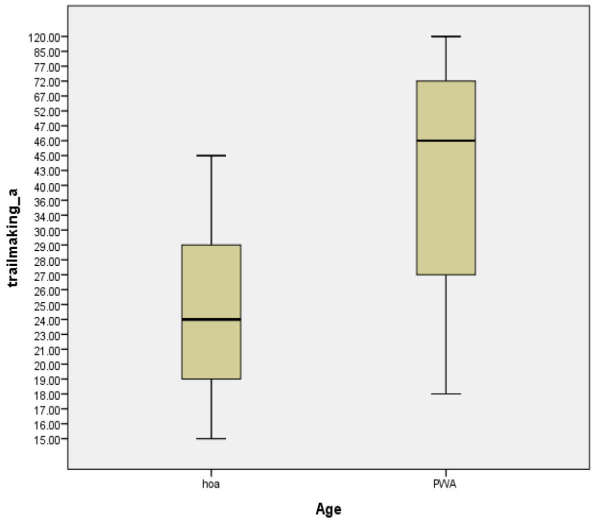
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30.00
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26.00
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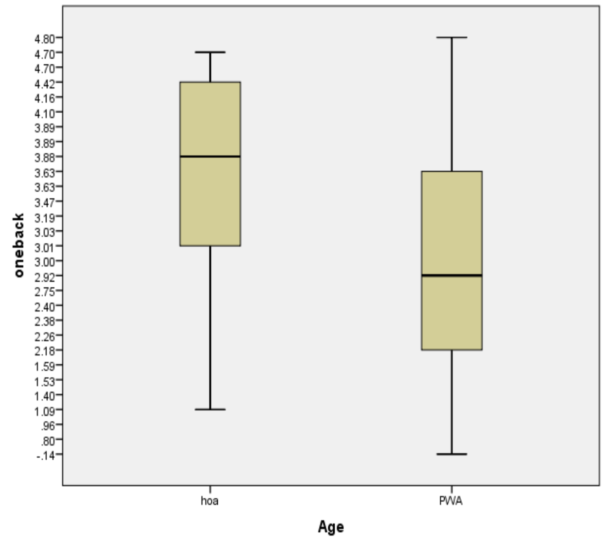
Age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3.03
3.01
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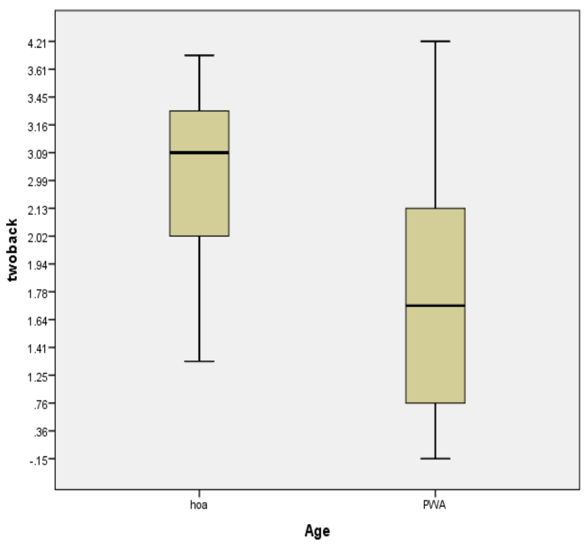
Age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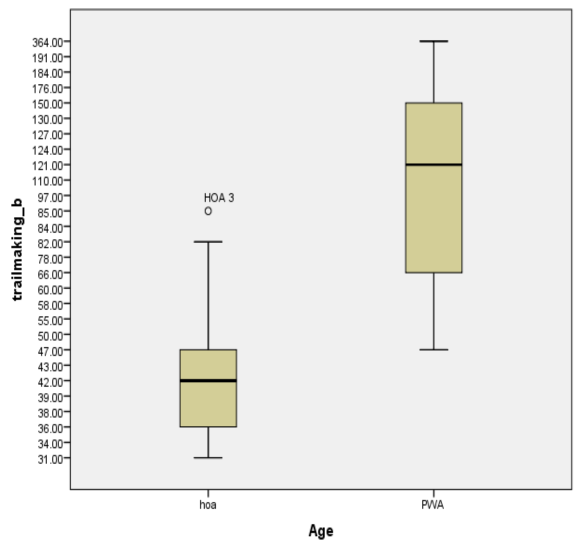
Age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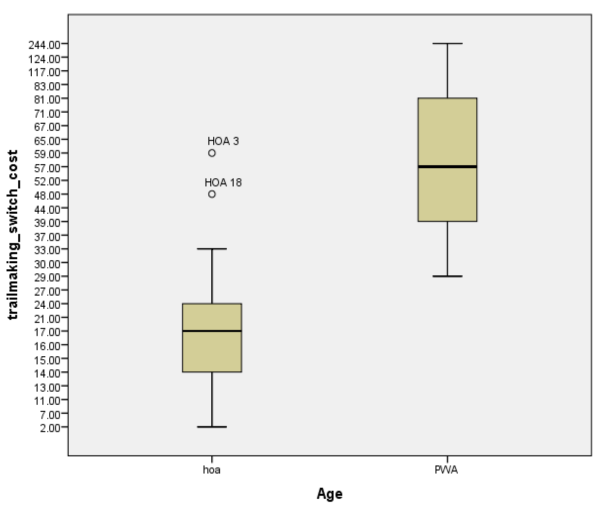
HOA 3
hoa
PWA
Age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29.00
27.00
24.00
21.00
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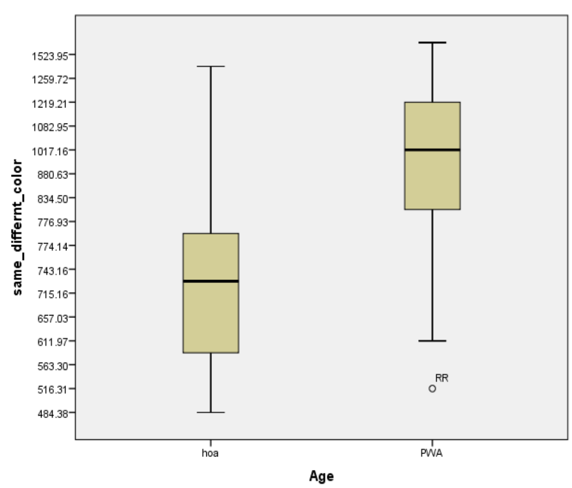
7.00
2.00
HOA 3
HOA 18
hoa
PWA
Age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RR
hoa
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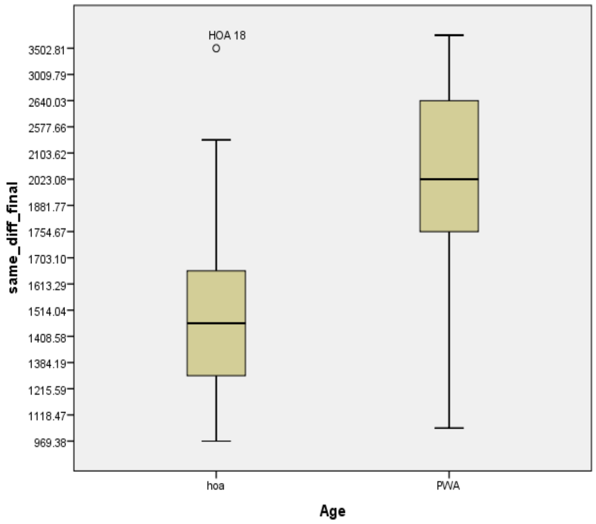
Age



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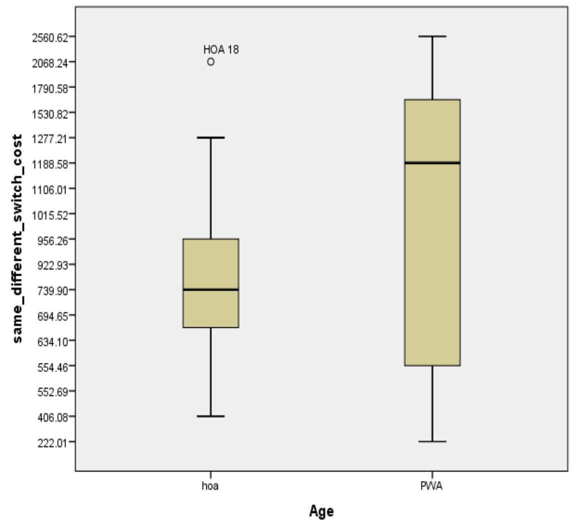
Age



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1015.52
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739.90
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634.10
554.46
552.69
406.08
222.01
same_different_switch_cost
hoa
PWA
Age

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