ESTIMATES OF FUNCTIONAL CEREBRAL HEMISPHERIC DIFFERENCES IN MONOLINGUAL AND BILINGUAL PEOPLE WHO STUTTER

A thesis submitted in partial fulfilment of the requirements

for the Degree of Doctor of Philosophy

in Speech and Language Sciences

Myriam Kornisch

Department of Communication Disorders

University of Canterbury

2015

Abstract

Purpose: The aim of this research was to examine the relationship between stuttering and bilingualism to hemispheric asymmetry for the processing and production of language.

Methods: A total of 80 native speakers of German were recruited for the study, ranging in age from 15 to 58 years. Out of those 80 participants, 40 participants were also proficient speakers of English as a second language (L2). The participants were organised into four speaker groups (20 per group) according to language ability and speech status, consisting of monolinguals who stutter (MWS), monolinguals who do not stutter (MWNS), bilinguals who stutter (BWS), and bilinguals who do not stutter (BWNS). Each of the four groups comprised 12 males and 8 females. All participants completed a battery of behavioural assessments measuring functional cerebral hemispheric asymmetry during language processing and production. The behavioural tests included (1) a dichotic listening paradigm, (2) a visual hemifield paradigm, and (3) a dual-task paradigm.

Results: Overall, the results showed no significant differences in language lateralisation between participant groups on the three behavioural tests. However group differences were identified in regard to executive functions on the visual hemifield and dual-task paradigms. Both bilingual groups showed significantly faster reaction times and fewer errors than the two monolingual groups on the visual hemifield paradigm. The bilingual groups also performed similarly on the dual-task paradigm, while the MWS group tended to show greater task disruption. No meaningful relationship was found between stuttering severity and the majority of results obtained for the test conditions. However, all four language modalities were found to correlate significantly with results obtained for the visual hemifield and dual-task paradigms, suggesting that performance on these tests increased with higher L2 proficiency.

Conclusion: Although no differences in language lateralisation were found, it appears that bilingualism had a greater influence on functional cerebral hemispheric processing than stuttering. A prevailing finding was that bilingualism seems to be able to offset deficits in executive functioning associated with stuttering. Brain reserve and cognitive reserve are thought to have a close interrelationship with the executive control system. Cognitive reserve may have

been reflected in the present study, resulting in a bilingual cognitive advantage. Hence, the results of the present study lend support to previous findings implicating the benefits of bilingualism.

Acknowledgements

First and foremost, I would like to express my deepest gratitude to my ‘Doktorvater’ (primary supervisor) Professor Michael Robb. His guidance and support, coupled with his enthusiasm, encouragement, and genuine care have been a constant source of inspiration for me. Next, a huge thank you to my two secondary supervisors, Professor Maggie-Lee Huckabee and Professor Richard Jones, whose advice and feedback have been immensely helpful and greatly appreciated. The expertise and directions offered by all members of my supervisory team have been exceptional and invaluable throughout my doctoral studies.

I must also give my gratitude to Professor Greg O’Beirne for providing me with the dichotic listening paradigm, as well as to my friend Dr. Mathieu Nancel, who developed the visual hemifield and dual-task paradigms. Furthermore, I am very grateful to my friend, Dr. Fabian Scheipl, for his assistance with the statistical analysis.

I would like to acknowledge the Deutscher Bundesverband für Logopädie e. V. (dbl), Bundesvereinigung Stottern & Selbsthilfe e. V. (BVSS), stutter support groups, and speech-language pathologists in Germany, all of whom have provided support in participant recruitment. Specifically, I would like to thank Elvira Aigner, Claudia Carboni-Lichtwald, Katrin Ladanyi, and Martina Duske who also generously provided their facilities for participant assessments. Moreover, a very heartfelt thanks goes to all the participants who volunteered to be part of this research. Their contribution and commitment made this study possible in the first place and is greatly appreciated. There are many more people without whom the completion of this PhD research would not have been possible. While there are far too many to name individually, I am truly grateful to everyone who has so very kindly given me their time and assistance.

In addition, thanks to all my friends in New Zealand and Germany who stuck with me throughout the past years as a doctoral candidate. In particular, a special thank you to my very best friend Evelyn, who I can always count on, who I never have to explain myself to, and who believes in me no matter what.

I also owe a great deal to my partner, Christoph, who has sacrificed a lot in maintaining our long-distance relationship over the last couple of years. He has been the most understanding person

anyone could wish for, especially during the final few stressful months of writing up. His belief in me has been a great source of comfort and motivation, which helped me to stay focused during the lengthy data collection process and all these long hours in front of the computer.

Finally, I would like to thank my family back in Germany. They have fully supported and encouraged me in my decision to move to New Zealand and pursue a PhD, for which I am extremely grateful. In particular, a special thank you to my mum, sister, and Stiefhexe. However, my deepest gratitude goes to my dad, who has not only taught me the value of education but also enabled me to pursue the career of my choice.

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Abbreviations

ANOVA	Analysis of variance
AWNS	Adults who do not stutter
AWS	Adults who stutter
BWNS	Bilinguals who do not stutter
BWS	Bilinguals who Stutter
CI	Confidence interval
CT	Computerized tomography
CV	Consonant-vowel
CWNS	Children who do not stutter
CWS	Children who stutter
EEG	Electroencephalography
fMRI	Functional magnetic resonance imaging
fNIRS	Functional near-infrared spectroscopy
IID	Interaural intensity difference; ‘cross-over point’
JND	Just noticeable difference
L=R	Equal interaural intensity levels for the left and right ear
L1	First language
L2	Second language
LEA	Left ear advantage
LI	Laterality index
LVF	Left visual hemifield
MEG	Magnetoencephalography
MRI	Magnetic resonance imaging
MWNS	Monolinguals who do not stutter
MWS	Monolinguals who stutter
ND	Normalised difference
PCS-CL	Percent change score during counting and tapping with the left hand
PCS-CR	Percent change score during counting and tapping with the right hand
PCS-RL	Percent change score during reading and tapping with the left hand

PCS-RR	Percent change score during reading and tapping with the right hand
PET	Positron emission tomography
PWNS	People who do not stutter
PWS	People who stutter
REA	Right ear advantage
RVF	Right visual hemifield
SLP	Speech-language pathologist
SPECT	Single photon emission computed tomography
VHF	Visual hemifield
WHO	World Health Organization

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1. Introduction

It is estimated that approximately 50% of the world's population is bilingual (Bhatia & Ritchie, 2006; Van Borsel, 2011) and that stuttering is present in all cultures and languages with an average prevalence of about 1% globally (Bloodstein & Bernstein Ratner, 2008). Therefore, bilinguals who stutter (BWS) represent a considerable portion of the world's population. In spite of this, research assessing BWS is still in its early stages and published data are limited. Most examinations of stuttering have focused on monolingual speakers and have not taken into account that participants might be proficient in more than one language.

Considerable progress has been made in the field of stuttering in terms of understanding the disorder, yet the aetiology of developmental stuttering remains unknown. The early suggestion that stuttering is a result of brain dysfunction (Orton, 1928; Orton & Travis, 1929; Travis, 1931, 1978) has since received support from various neuroimaging studies that have revealed functional and structural brain changes in monolinguals who stutter (MWS) (Beal, Gracco, Lafaille, & De Nil, 2007; Biermann-Ruben, Salmelin, & Schnitzler, 2005; Blomgren, Nagarajan, Lee, Li, & Alvord, 2003; Braun et al., 1997; De Nil et al., 2008; Foundas et al., 2003; Fox et al., 2000; Neumann et al., 2003; Salmelin, Schnitzler, Schmitz, & Freund, 2000; Van Borsel, Achten, Santens, Lahorte, & Voet, 2003). For example, MWS have been found to show disparities in the level of activation between the left and right hemispheres in the motor and auditory regions compared to monolinguals who do not stutter (MWNS). Specifically, they appear to have atypical processing in the form of right hemispheric language dominance (Foundas, Corey, Hurley, & Heilman, 2004; Sussman, 1982; Szelag, Garwarskakolek, Herman, & Stasiek, 1993). Although a number of factors, such as severity of stuttering, sex, age, and handedness, seem to play a role in the presentation of atypical hemispheric asymmetry (Brosch, Haege, Kalehne, & Johannsen, 1999; Foundas et al., 2004; Szelag et al., 1993), the findings indicate that MWS show some degree of divergent patterns of cerebral language lateralisation. Interestingly, divergent patterns of language dominance have also been found in bilinguals who do not stutter (BWNS) compared to MWNS (Albert & Obler, 1978; Hull & Vaid, 2007; Kovelman, Baker, & Petitto, 2008). These divergent patterns appear to be dependent on the age of second language acquisition (Hull & Vaid, 2007). The cerebral language lateralisation behaviour in BWS has yet to be assessed.

BWS represent a unique group to be assessed not just with respect to stuttering but also bilingualism. The present study was designed to contribute new data to the fields of stuttering and bilingualism with specific reference to cerebral language lateralisation. The present study had four major objectives: (a) to provide a further explanation of the nature of stuttering; (b) to provide novel information on the effects of stuttering in combination with bilingualism on cerebral hemispheric asymmetry; (c) to explore possible associations between stuttering and bilingualism; and (d) to determine the predictive value of these factors on cerebral hemispheric asymmetry.

2. Literature Review

2.1 Developmental Stuttering

Developmental stuttering is a fluency disorder that is prevalent in approximately 1% of the population, with a sex ratio of males to females of about 3:1 (Bloodstein & Bernstein Ratner, 2008). The sex ratio has been attributed to both nature (physical maturation, sex-linked patterns of genetic transmission, sex differences in constitution) and nurture (speech and language development, differences in parents' expectations and attitudes with regard to girls and boys), but more so to the former (Kidd, Kidd, & Records, 1978). Mansson (2000) found a positive family history of stuttering for 67% of the children presenting with persistent stuttering, which indicates a genetic component in the incidence of stuttering (Viswanath, Lee, & Chakraborty, 2004).

The onset of stuttering typically occurs around three years of age (Bernstein Ratner & Silverman, 2000; Mansson, 2000; Yaruss, LaSalle, & Conture, 1998) and it is estimated that 68-74% of children recover naturally in early childhood (Mansson, 2000; Ryan, 2001; Yairi & Ambrose, 1999). According to Yairi and Ambrose (1999), girls show not only higher recovery rates than boys but also recover at earlier ages. Natural recovery has also been reported to occasionally occur during adolescence and adulthood, although it is difficult to prove that it is not associated with some type of assistance (Finn, 2004). Although stuttering typically develops in early childhood (i.e. developmental stuttering), it can also be acquired later in life (i.e. acquired stuttering) due to neurogenic, psychogenic, or drug-induced causes (Van Borsel, 2014). However, the present PhD thesis only refers to developmental stuttering.

2.1.1 Definition of Stuttering

There is no consistent definition of stuttering which identifies all of its symptoms (Bloodstein & Bernstein Ratner, 2008). According to Yairi and Seery (2011), scholars have defined stuttering as either a speech event or a disorder. The speech event refers to what a person is doing when talking, while the disorder refers to what a person is or has, including physiological, emotional, cognitive and social aspects.

2.1.1.1 Stuttering as a Speech Event

According to this conceptualization, stuttering is defined as an observable speech phenomenon and only occurs in the context of attempting to speak (Yairi & Seery, 2011). Wingate (1964, p. 488) offered a definition of stuttering in which the first of three parts focused on core speech features defining stuttering as a speech event. The definition is as follows:

> “(a) Disruption in the fluency of verbal expression, which is (b) characterized by involuntary, audible or silent, repetitions or prolongations in the utterance of short speech elements, namely: sounds, syllables, and words of one syllable. These disruptions (c) usually occur frequently or are marked in character and (d) are not readily controllable.
>
> Sometimes the disruptions are (e) accompanied by accessory activities involving the speech apparatus, related or unrelated body structures, or stereotyped speech utterances. These activities give the appearance of being speech-related struggle.
>
> Also, there are not infrequently (f) indications or reports of the presence of an emotional state, ranging from a general condition of ‘excitement’ or ‘tension’ to more specific emotions of a negative nature such as fear, embarrassment, irritation, or the like. (g) The immediate source of stuttering is some incoordination expressed in the peripheral speech mechanism; the ultimate cause is presently unknown and may be complex or compound.”

These disruptions occur only rarely in the speech of normally fluent people; however, the frequent occurrence of these speech events conveys the impression of stuttering (Yairi & Seery, 2011). A more recent definition of stuttering as a speech event offers additional characteristics and has been proposed by Guitar (2006, p. 13). The definition is as follows:

> “Stuttering is characterized by an abnormally high frequency and/or duration of stoppages in the forward flow of speech. These stoppages usually take the

> form of (1) repetitions of sounds, syllables, or one-syllable words, (2) prolongations of sounds, or (3) blocks of airflow or voicing in speech.“

2.1.1.2 Stuttering as a Disorder

The background for defining stuttering as a disorder is its multidimensionality. A large body of research has found considerable evidence of functional and structural neural abnormalities in speech-motor control for people who stutter (PWS) (Alm, Karlsson, Sundberg, & Axelson, 2013; Busan et al., 2013; Ludlow & Loucks, 2003; Neef, Hoang, Neef, Paulus, & Sommer, 2015; Smith, Goffman, Sasisekaran, & Weber-Fox, 2012; Watkins, Smith, Davis, & Howell, 2008). For example, both Alm et al. (2013) and Neef et al. (2015) provided support for the hypothesis that stuttering is associated with left hemisphere motor impairment. However, stuttering involves overt speech characteristics of dysfluent speech, as well as physical concomitants, physiological activity, affective features, cognitive processes, and social dynamics (Yairi & Seery, 2011). Mulligan, Anderson, Jones, Williams, and Donaldson (2001, 2003) highlight this by noting the presence of involuntary movements and tics. Jones, White, Lawson, and Anderson (2002) noted impaired dynamic visuoperception and impaired visuomotor tracking in PWS. These studies strongly support that stuttering is a neurological disorder with deficits beyond speech (Jones et al., 2002; Mulligan et al., 2001, 2003).

Van Riper (1971, p. 15) proposed that “a stuttering behavior consists of a word improperly patterned in time and the speaker’s reaction thereto”. In other words, stuttering temporally disrupts the unity of a word’s motor planning due to time distortions (e.g., repetitions, prolongations, gaps, insertions) of the component sounds or syllables comprising the word (Van Riper, 1971). The World Health Organization (WHO) defines stuttering as “ disorders in the rhythm of speech, in which the individual knows precisely what he wishes to say, but at the time is unable to say it because of an involuntary, repetitive prolongation or cessation of a sound” (1977, p. 202).

2.1.2 Theories of the Aetiology of Stuttering

Numerous theories have been proposed in an attempt to describe the nature and aetiology of stuttering (Etchell, Johnson, & Sowman, 2014; Forster & Webster, 2001; Garcia-Barrera &

Davidow, 2015; Johnson, 1942; Packman, Code, & Onsjow, 2007; Perkins, Kent, & Curlee, 1991; Postma & Kolk, 1993; Siegel, 2000; Starkweather, 1995; Travis, 1978); however, there is no unified theory that accounts for all aspects of stuttering (Robb, 2010). In general, theories about stuttering distinguish between the distal cause (why someone has the disorder) and the proximal cause (why someone stutters in a particular moment) (Attanasio, Onslow, & Packman, 1998). It is now widely believed that the distal cause of stuttering is genetic (Domingues et al., 2014; Felsenfeld et al., 2000) and/or neurological (Chang, 2014; Ingham, Ingham, Finn, & Fox, 2003). For example, stuttering has been linked to (a) a family history of stuttering (Poulos & Webster, 1991; Yairi, Ambrose, & Cox, 1996), (b) differences in motor control (Forster & Webster, 2001; Jones et al., 2002), and (c) divergent patterns of brain activity (Brown, Ingham, Ingham, Laird, & Fox, 2005; Ingham et al., 2004).

Theories considering a physiological component in the development of stuttering have been described as breakdown theories. Stuttering is attributed to the effects of early environmental stress, with neurological predisposition playing an important role in its development (Bloodstein & Bernstein Ratner, 2008). Thus, PWS have decreased physiological capacities to effectively coordinate speech, which might involve perceptual, motor, or other cerebral deficits (Andrews et al., 1983). A physiological dysphemic breakdown theory, first proposed by Orton and Travis (Orton, 1928; Orton & Travis, 1929; Travis, 1931, 1978), is the well-acknowledged cerebral dominance model. Travis (1931) states that children are predisposed to stutter because neither half of the cerebral cortex is dominant in controlling the motor activity of the speech production system. It is sometimes also referred to as the handedness model as it builds a link between cerebral dominance, handedness and stuttering. The cerebral dominance model is also supported by Forster and Webster (2001), who offered a model which is basically a modified version of the Orton and Travis model. They proposed that a labile system of hemispheric activation results in an over-activation of the right hemisphere for functions usually dealt with by the left hemisphere, which then interferes with efficient left hemisphere control of speech-motor tasks. Other representations of the breakdown theory are the motor model by Zimmermann (1980) and the sensory-motor model by Andrews et al. (1983), which both consider stuttering to be a motor control disorder. In addition, Andrews et al. (1983) also emphasize the importance of central processing involved in speech production.

Some other popular theories regarding stuttering include the (a) demands and capacities theory, (b) covert repair theory and (c) neuropsycholinguistic theory. The demands and capacities theory (Starkweather, 1995; Starkweather, Gottwald, & Halfond, 1990) examines the interactions between genetic and environmental influences on stuttering development. According to Starkweather (1987), stuttering may be the result of an overload of cognitive, linguistic, motor or emotional capacities for fluent speech, induced by fluency demands from the child's social environment. In contrast, the covert repair theory proposed by Postma and Kolk (1993) suggests that dysfluencies originate from deficits in the internal phonological encoding system. That is, the ability to produce error-free speech programs is disordered in PWS. Thus, stuttering is a result of repeated covert repairs of internal speech errors prior to speech-motor execution. Furthermore, Perkins et al. (1991) proposed the neuropsycholinguistic theory, which suggests that dysfluencies in PWS reflect fewer available neural resources. The interaction of speech disruption and time pressure is thought to play a central role in dysfluent speech production. It is assumed that stuttering is the result of a timing issue between the linguistic formulation of an utterance and the simultaneous execution of motor speech. In other words, the neural resources required to produce fluent speech are insufficient in PWS.

2.1.3 Brain Differences

Brain imaging procedures allow more sophisticated analyses of brain functions and structures. Neuroimaging studies of stuttering are working toward consensus in terms of the underlying neural mechanisms associated with the disorder. A number of researchers have used these neuroimaging procedures to assess the brains of PWS during moments of fluency and dysfluency (Beal et al., 2007; Beal et al., 2015; Civier, Kronfeid-Duenias, Amir, Ezrati-Vinacour, & Ben-Shachar, 2015; De Nil, Kroll, & Houle, 2001; De Nil, Kroll, Kapur, & Houle, 2000; De Nil, Kroll, Lafaille, & Houle, 2003; Fox et al., 2000; Ingham et al., 2004; Joos, De Ridder, Boey, & Vanneste, 2014; Klein, Mok, Chen, & Watkins, 2014; Sommer, Koch, Paulus, Weiller, & Buchel, 2002). Although the specific neurobiological basis is unknown, research into stuttering provides increasing evidence of brain differences in PWS relative to fluent-speaking controls (De Nil et al., 2001; Fox et al., 2000; Sommer et al., 2002). In general, it has been found that:

- The neural system underlying stuttered speech is different from that of normal speech;

- Motor speech and language production areas show differences in levels of activation;
- Stuttering is not necessarily related to one structure or neural pathway;
- Stuttering is most notably associated with hemispheric asymmetry (De Nil, 2004; Kent, 2000; Ward, 2006).

More specifically, PWS show functional abnormalities in the form of (1) over-activity in the right hemisphere centred on the right inferior frontal gyrus, (2) under-activity of auditory areas in the temporal lobe, (3) atypical activation of subcortical structures involved in the control of movements (basal ganglia, cerebellum), as well as structural abnormalities in the frontal and temporal lobes and the white matter connections between them (Watkins & Klein, 2011; Watkins et al., 2008). A number of brain differences have also been found in recent studies investigating children who stutter (CWS) (Chang, 2014; Chang & Zhu, 2013; Sato et al., 2011; Sowman, Crain, Harrison, & Johnson, 2014; Weber-Fox, Wray, & Arnold, 2013).

2.1.3.1 Brain Function

Atypical Cerebral Lateralisation

Among PWS, increased right hemisphere activity during language processing and production is usually found in the frontal opercular part of the frontal lobe, sometimes extending to the anterior insula and the orbitofrontal cortex (Brown et al., 2005; Kell et al., 2009; Watkins et al., 2008). It has further been suggested that stuttering is associated with left hemisphere motor impairment (Alm et al., 2013; Neef et al., 2015). Neef et al. (2015) proposed that speech-motor plans are primarily controlled in the left motor cortex in people who do not stutter (PWNS), and that this left hemispheric asymmetry is not evident in PWS. This implies that stuttering may be a result of atypical motor cortex activation.

Interestingly, a more typical left lateralised activation pattern can be achieved through successful fluency therapy, which may reduce the right inferior frontal gyrus over-activity or increase left hemisphere activity (De Nil et al., 2003; Kell et al., 2009; Kroll, De Nil, Kapur, & Houle, 1997; Neumann et al., 2003). Therefore, some researchers speculate that the right inferior frontal activation might reflect a compensatory mechanism of long-term stuttering rather than bilateral or right hemisphere language dominance (Preibisch et al., 2003). This contention is further supported by Sowman et al. (2014) who assessed language lateralisation in preschool CWS and children who do not stutter (CWNS). These researchers found no group differences and observed that brain activation was significantly left-lateralised in all children during a picture naming task.

There is also evidence that atypical hemispheric language lateralisation begins to emerge near the onset of developmental stuttering (Sato et al., 2011; Weber-Fox et al., 2013). Sato et al. (2011) found differences in language lateralisation between CWS and CWNS, as well as adults who stutter (AWS) and adults who do not stutter (AWNS) on a phonological and prosodic contrast task. Specifically, a clear left hemisphere advantage was found for perception of phonemic contrasts compared to the prosodic contrasts in AWNS and CWNS, whereas AWS and CWS showed no ear advantage during either task. The reasons for atypical lateralisation of language for PWS are still a matter of debate.

Atypical Auditory-Motor Interaction

Fluent speech production requires successful auditory processing, motor planning, and motor execution (Hickok & Poeppel, 2007). That is, a well-established connection between the posterior (auditory cortex) and anterior (motor cortex) parts of the brain is essential to coordinate speech production. However, PWS have been found to demonstrate over-activation of motor regions in the right hemisphere (Chang, Kenney, Loucks, & Ludlow, 2009; Fox et al., 1996), as well as bilateral reduced activity of the auditory cerebral cortices (Braun et al., 1997; Brown et al., 2005; Ingham, 2001). Brown et al. (2005) proposed the phenomenon of ‘motor efference copy’ as a unifying account of the decrease in brain activity for auditory processing observed in PWS. Efference copy refers to motor control and is crucial for motor adaptations. It can be described as a signal from motor to sensory areas and the result is considered to represent the precise sensory consequences of each motor action (Niziolek, Nagarajan, & Houde, 2013; von Holst & Mittelstaedt, 1950).

Atypical Cerebellar and Basal Ganglia Function

Neuroimaging studies have revealed a large area of over-activity in the midbrain during speech in PWS irrespective of fluency (Watkins et al., 2008), as well as considerably higher levels of dopamine in several cortical and subcortical structures (Wu et al., 1997). A number of researchers have suggested atypical basal ganglia and cerebellar function to be involved in stuttering (Alm, 2004; Craig-McQuaide, Akram, Zrinzo, & Tripoliti, 2014; De Nil et al., 2001; Giraud et al., 2008; Ingham et al., 2004; Wu et al., 1995). For example, Fox et al. (1996) observed increased cerebellar activation with right hemispheric cerebral dominance in PWS. Atypical basal ganglia function has also been implicated for PWS. For example, Wu (1995) found PWS, compared to PWNS, show decreased activity in the caudate nucleus during both fluent and dysfluent speech. Alm (2004) reviewed the possible relationship between basal ganglia impairment and dopamine in developmental stuttering. He proposed that basal ganglia thalamocortical motor circuits through the putamen are likely to play a key role. That is, stuttering is a disorder of motor timing (Kent, 1984; Van Riper, 1971), and the core dysfunction in stuttering is an impaired ability of the basal ganglia to produce timing cues for the initiation of the next motor segment in speech (Cunnington, Bradshaw, & Iansek, 1996). Furthermore, sex differences have also been observed. Ingham et al. (2004) reported positive correlations between stuttering and basal ganglia activity in females. In contrast, stuttering was found to correlate with cerebellum activity in males.

2.1.3.2 Brain Structure

A number of studies have assessed brain structure in regard to grey and white matter in PWS (Beal, Gracco, Brettschneider, Kroll, & De Nil, 2013; Beal et al., 2015; Cai et al., 2014; Chang, Erickson, Ambrose, Hasegawa-Johnson, & Ludlow, 2008; Chang, Zhu, Choo, & Angstadt, 2015; Choo, Chang, Zengin-Bolatkale, Ambrose, & Loucks, 2012; Civier et al., 2015; Connally, Ward, Howell, & Watkins, 2014). Watkins and Klein (2011) reviewed several studies which investigated brain structure in developmental stuttering and concluded that the most consistent differences associated with developmental stuttering were in white matter microstructure. According to Chang et al. (2008), risk for childhood stuttering is associated with reduced grey matter volume in speech-related areas, while persistent stuttering is linked to decreased white matter underlying the sensorimotor cortex in the left hemisphere.

Beal et al. (2015) assessed both AWS and CWS, compared to controls, and observed abnormal grey matter volume in the posterior part of Broca’s area. The grey matter in this area of the brain failed to show the typical maturational pattern of gradual thinning with age across the lifespan.

Chang et al. (2008) found reduced grey matter volume in the bilateral temporal regions (planum temporale) for CWS. Interestingly, they observed no left to right asymmetry differences. This is in contrast to findings in AWS that show bilateral increases in the planum temporale and atypical right to left asymmetry (Foundas, Bollich, Corey, Hurley, & Heilman, 2001).

Both AWS and CWS have been found to have decreased white matter in the corpus callosum and in tracts that link auditory and motor areas (Beal et al., 2013; Cai et al., 2014; Chang et al., 2008; Chang et al., 2015; Civier et al., 2015; Connally et al., 2014). For example, Civier et al. (2015) observed reduced myelination in the corpus callosum in AWS compared to AWNS and found that greater decreases in white matter were associated with greater dysfluency. It was suggested that these structural changes might reflect a maladaptive decrease in interhemispheric inhibition, which could in turn result in the atypical activation of the right frontal cortex in PWS. Furthermore, structural white matter changes, such as a reduction in white matter volume of the corpus callosum, have also been found for CWS (Beal et al., 2013).

2.1.4 Summary

Developments in functional neuroimaging technology have enabled researchers to investigate some of the neurological factors associated with developmental stuttering. Although developmental stuttering is still not entirely understood and the precise neural basis of stuttering remains elusive, recent research provides increasing evidence of brain differences in PWS compared to fluent speakers. A consistent finding in most studies has been that PWS demonstrate a strong tendency toward bilateral or right hemisphere cortical dominance during linguistic tasks. Abnormal brain activity associated with developmental stuttering has also been observed in the form of under-activity of the auditory cortex bilaterally and atypical activity in the basal ganglia and cerebellum. Thus, sensorimotor integration is considered to be abnormal in developmental stuttering. In addition, abnormalities in brain structure have been found that include differences in the grey and white matter density and structure. Therefore, it has also been suggested that stuttering is linked to difficulties with the initiation of motor programs, and that the observed under- and over-activation of cortical areas are a consequence of stuttering rather than a cause (Brown et al., 2005).

2.2 Bilingualism

It is estimated that approximately 50% of the world population is bilingual or multilingual (Bhatia & Ritchie, 2006). Therefore, in many countries, being bilingual is the norm rather than the exception. Goldstein and Kohnert (2005) identified several factors that influence second language acquisition in children. These factors include (a) the age at which a child receives input in each language, (b) the environment in which the language occurs, (c) the community support and social prestige of each language, (d) differences and similarities in the languages, and (e) individual factors such as motivation and language learning ability. Furthermore, it has been found that among adults, gender is an important factor in second language proficiency with females being more proficient than males (Andreou, Vlachos, & Andreou, 2005). According to Andreou et al. (2005), this can be explained by the general female superiority on verbal tasks based on differences in hemispheric specialisation for language function between females and males.

2.2.1 Definition of Bilingualism

The term bilingualism refers to functional knowledge of at least two languages, with possible variations of the degree of linguistic and communicative abilities across languages (Hull & Vaid, 2007). There are two general concepts related to bilingualism, which are (1) second language acquisition and (2) language proficiency (Bialystok, 2001; Kessler, 1984; Miller, 1984; Romaine, 1989).

2.2.1.1 Second Language Acquisition

The age at which an individual is exposed to a second language plays a crucial factor with respect to the level of bilingualism attained. Definitions of bilingualism vary, and there is no commonly agreed upon method of defining bilingualism. However, two types of second language acquisition have been identified: simultaneous bilingualism and sequential bilingualism (Krashen, 1987; Owens, 2008). According to Field (2011), simultaneous (or early) bilingualism refers to individuals that are introduced to both or all languages from birth, thus languages are acquired at the same time and considered to be first or native languages (L1). Sequential bilingualism refers to individuals that are introduced to a second language (L2) or more languages after they have already mastered a first language, which is also known as consecutive or late bilingualism.

2.2.1.2 Language Proficiency

Bilingualism can also be defined with respect to levels of language proficiency. Language proficiency is a term often used to indicate general ability in a language. It is not simply confined to spoken language but includes the four language modalities listening, speaking, reading, and writing (Lim, Rickard Liow, Lincoln, Chan, & Onslow, 2008). Field (2011, p. 145) provided the following definition of language proficiency:

> “A (highly) proficient speaker of English, for example, can use it for nearly every natural function of language, from informal usage in everyday speech to the formal usage necessary for academic purposes. In other words, he or she is conversant with a broad range of registers of speech. A person of limited or low proficiency has yet to develop the skills necessary for participating in a wide range of language activities. The term proficiency includes fluency (interacting rapidly over a broad range of topics) and accuracy (correctly, according to native- or near-native-speaker norms). In this sense, it is both a qualitative and quantitative measure.”

In addition, Hull and Vaid (2007, p. 1990) defined proficient bilinguals as “individuals whose language performance on standardized proficiency exams was reported at or above 85% accuracy, or who gave teacher- or self-ratings as ‘high’ on proficiency, and/or had five or more years of formal study of the language”.

2.2.2 Brain Differences

The brain function and structure of bilingual speakers has been examined in detail. Several researchers have suggested a neural signature of bilingualism (Indefrey, 2006; Kovelman et al., 2008; Mechelli et al., 2004; Olsen et al., 2015). Abutalebi et al. (2012) conducted a combined functional and structural study and found that bilinguals required fewer neural resources since their brain showed better adaptation to deal with tasks involving cognitive conflicts. Specifically, they used the dorsal anterior cingulate cortex more efficiently than monolinguals to monitor non-linguistic cognitive conflicts. The dorsal anterior cingulate cortex, located in the limbic lobe, encompasses various specialised subdivisions that play key roles in cognitive, motor and visuospatial processing (Bush, Luu, & Posner, 2000). Abutalebi et al. (2012) also observed a positive correlation between brain activity and grey matter volume in bilingual participants. Overall, grey matter changes have typically been found in the left frontal and parietal regions, while parts of the corpus callosum have typically been found to show cortical white matter changes (Stein, Winkler, Kaiser, & Dierks, 2014). Interestingly, the neural networks linked to bilingualism have been found to overlap with the neural networks that typically decline with age.

2.2.2.1 Brain Function

The brain function of bilinguals has been found to differ from monolinguals (Grady, Luk, Craik, & Bialystok, 2015; Kim, Relkin, Lee, & Hirsch, 1997; Klein, Milner, Zatorre, Meyer, & Evans, 1995; Parker Jones et al., 2012; Perani et al., 2003; Rodriguez-Fornells, Rotte, Heinze, Nosselt, & Munte, 2002; Wartenburger et al., 2003). For example, Grady et al. (2015) assessed older monolingual and bilingual adults and observed increased brain activity in the frontoparietal control network for the bilingual group. These researchers proposed that the difference in brain network connectivity indicates that bilingual language experience may provide a neural advantage among the elderly.

Reverberi et al. (2015) investigated language control in right-handed sequential German-English bilinguals and found language-dependent differences in brain activity for the execution of speech in German (L1) versus English (L2). Neural activation was increased for L2 compared to L1 in the cingulate cortex and caudate nucleus, which are both areas that have also been linked to cognitive control. Li et al. (2015) suggested that bilingualism alters functional connectivity between control regions (i.e., cingulate cortex, left caudate nucleus) and language regions of the brain. Nevertheless, a number of researchers agree that the degree to which brain regions are involved in bilingual language processing is determined by several factors, such as age of L2 acquisition (Wartenburger et al., 2003) and language proficiency (Perani et al., 1998), as well as by the language assessed and the type of language processing skill engaged (Frenck-Mestre, Anton, Roth, Vaid, & Viallet, 2005; Tan et al., 2003; Xu et al., 2006). For example, a significantly greater increase in the blood oxygenation level-dependent signal in the left frontal cortex (Brodman area 45) was found in simultaneous bilinguals compared to monolinguals (Kovelman et al., 2008). For sequential bilinguals compared to monolinguals, higher brain activation was found in several regions of the left hemisphere (Parker Jones et al., 2012). Furthermore, Klein et al. (1995) found an increased activation in the left basal ganglia when an output response was required to be produced in L2.

2.2.2.2 Brain Structure

Various anatomical changes in brain structure associated with bilingualism have also been observed (Abutalebi, Canini, Della Rosa, Green, & Weekes, 2015; Abutalebi et al., 2012; Garcia-Penton, Fernandez, Iturria-Medina, Gillon-Dowens, & Carreiras, 2014; Grogan, Green, Ali, Crinion, & Price, 2009; Klein et al., 2014; Mechelli et al., 2004; Olsen et al., 2015; Pliatsikas, Moschopoulou, & Saddy, 2015; Stein et al., 2012). For example, Mechelli et al. (2004) found greater grey matter volume in bilinguals compared to monolinguals, in simultaneous bilinguals compared to sequential bilinguals, and in proficient bilinguals compared to non-proficient bilinguals. Thus, increased grey matter appeared to be linked to increased language competence. Several researchers observed an increase in grey matter density for bilinguals while monolinguals showed an age-related decrease (Abutalebi et al., 2014; Abutalebi, Guidi, et al., 2015). Specifically, these differences have been observed in the anterior temporal lobe, anterior cingulate cortex, and prefrontal cortex. The findings have been taken to suggest that bilingualism might provide a so called ‘neural brain reserve’ for aging populations that protects against age-related cognitive decline.

The neural brain reserve has also been observed for white matter integrity. For example, Luk, Bialystok, Craik and Grady (2011) found more white matter volume in the corpus callosum for older bilingual than monolingual adults. White matter changes have been noted in various bilingual groups, including simultaneous bilingual adults (Garcia-Penton et al., 2014), sequential bilingual adults (Pliatsikas et al., 2015), as well as simultaneous and sequential bilingual children (Mohades et al., 2012; Mohades et al., 2015). Thus, it appears that bilingualism enhances structural connectivity between brain areas.

2.2.3 Summary

Two general concepts have been suggested to play a key role in defining bilingualism. Those concepts include the age of second language acquisition and the level of language proficiency. Results of neuroimaging studies have yielded inconsistent results with respect to language lateralisation. However, a consistent finding has been that the brains of bilinguals are different from monolinguals. Bilingualism appears to provide some form of protection against age-related cognitive and structural brain decline.

2.3 Stuttering and Bilingualism

2.3.1 Occurrence of Stuttering in Bilinguals

Findings suggest that stuttering is more prevalent among bilingual than monolingual speakers (Travis, Johnson, & Shover, 1937), and that young children learning more than one language tend to be at a greater risk of stuttering (Howell, Davis, & Williams, 2009; Karniol, 1992). For instance, Travis et al. (1937) assessed a total of 4827 children (2405 boys, 2422 girls), about half of whom were multilingual. They found that stuttering prevalence was lower in monolinguals (1.8%) than in multilinguals, with trilinguals (2.4%) surprisingly showing less stuttering than bilinguals (2.8%). However, the evidence for this contention is debatable, particularly since the findings were based on a single assessment. Furthermore, bilingual CWNS have been found to demonstrate more stuttering-like speech dysfluencies than monolingual CWNS (Byrd, Bedore, & Ramos, 2015). Thus, bilingual speakers are at higher risk of a false positive identification in the diagnosis of stuttering. A more recent investigation of stuttering and bilingualism suggested that there is no difference between bilingual and monolingual speakers in terms of stuttering risk (Au-Yeung, Howell, Davis, Charles, & Sackin, 2000). Instead, it was reported that the age of second language acquisition might affect the chances of developing a stutter to some degree, with children around three years of age being most vulnerable.

Shenker (2002) describes how bilingualism affects fluency and pointed out that temporarily increased dysfluency may be triggered in bilingual children when they (a) use vocabulary from two languages in one sentence, (b) have difficulties finding the correct word to express ideas, and (c) have difficulty using grammatically complex sentences in one or both languages. Furthermore, adding a second or third language between three and five years of age may cause stuttering to increase when the child is not proficient in L1 (Shenker, 2002). Karniol (1992) proposed that the higher percentage of stuttering noted in bilingual children might be the function of a syntactic overload, thus, the high demands on the children's functional systems may cause a breakdown manifested as stuttering.

Nwokah (1988) proposed three possibilities of how stuttering manifests in BWS: (1) stuttering is demonstrated in only one language, (2) stuttering is demonstrated in both languages with a similar pattern of distribution across languages (same-hypothesis), and (3) stuttering is demonstrated in both languages but with a different pattern of distribution across languages (different-hypothesis). However, stuttering occurring in only one language in bilinguals is rather uncommon, and in most cases stuttering occurs in all languages but frequency and severity in each language are affected to a different extent (Van Borsel, Maes, & Foulon, 2001). A number of studies support this contention (Bernstein Ratner & Benitez, 1985; Howell et al., 2009; Jankelowitz & Bortz, 1996; Jayaram, 1983; Taliancich-Klinger, Byrd, & Bedore, 2013), and previous studies generally indicated a higher rate of stuttering in the less proficient language (Ardila, Ramos, & Barrocas, 2011; Lim, Lincoln, Chan, & Onslow, 2008; Schaefer & Robb, 2012). For example, Schaefer and Robb (2012) reported a higher frequency of stuttering in L2 compared to L1 in sequential German-English bilingual AWS. These researchers suggested that their findings might be due to language proficiency differences. Thus, the greater cognitive and linguistic demands of the less proficient L2 might represent an additional load on the speech-motor system, resulting in an increase of dysfluencies. Nevertheless, it should be noted that Coalson, Pena, and Byrd (2013) found the description of multilingual participants who stutter in the literature to be inconsistent. These researchers concluded that this was due to information being based on single case studies, the large heterogeneity of BWS, and the manner in which bilingualism has been defined.

2.3.2 Diagnosis of Stuttering in Bilinguals

According to Roberts and Shenker (2007), appropriate stuttering assessment of BWS involves several components. These components include (1) a complete language history, (2) collection of speech samples in each language spoken, and (3) reliable analyses of these speech samples. However, the clinical assessment of bilingual speakers poses a number of challenges and often requires the adaptation of standard assessments due to the differential presentation of stuttering across languages. There is a considerable mismatch between bilingual speech-language pathologists (SLP) and languages spoken by patients. A recent Australian study found that the majority of SLPs were not proficient in a second language; thus, English was the primary language used during assessment and administration of tests (Williams & McLeod, 2012). Moreover, the surveyed SLPs further reported to have limited resources to distinguish whether a speech and language difference is due to a disorder or bilingualism. This may be especially problematic for SLPs working in the field of stuttering since difficulties in formulating utterances might be mistaken as dysfluent speech.

Furthermore, the SLP might be unable to detect some of the characteristics of stuttering moments due to being unfamiliar with a particular language spoken by a patient. Several researchers addressed the role of language familiarity in bilingual stuttering assessment (Einarsdottir & Ingham, 2009; Lee, Robb, Ormond, & Blomgren, 2014; Van Borsel, Leahy, & Pereira, 2008; Van Borsel & Pereira, 2005). The combined results of those studies indicated that stuttering could be accurately identified regardless of language familiarity. However, it appears that native speakers are more competent in regard to providing specific information on the characteristics of stuttered speech (e.g., stutter type) than non-native speakers (Van Borsel & Pereira, 2005). Furthermore, the importance of closeness of the unfamiliar language to the native language has also been observed to affect accuracy (Van Borsel et al., 2008). Therefore, it might be beneficial to seek the opinion of a fluent speaker to provide additional information in the second language assessed. Alternatively, adolescent and adult patients as well as parents of CWS are often able to provide helpful information about differences between their spoken languages (Roberts & Shenker, 2007).

2.3.3 Summary

In summary, there is a growing body of research investigating BWS in regard to prevalence, manifestation, and stuttering assessment. Furthermore, there is substantial research examining the brain behaviour of MWS compared to MWNS. There is also a body of research comparing the brain behaviour of bilingual speakers to monolingual speakers. At present, there is an absence of information regarding the brain behaviour of BWS. Studies assessing BWS would contribute a better understanding of the nature of stuttering, as well the nature of bilingualism.

2.4 Cerebral Hemispheric Asymmetry

2.4.1 Role of Corpus Callosum

The concept of hemispheric lateralisation for language is widely acknowledged (Broca, 1865; Davidson & Hugdahl, 1995; Hellige, 1993; Hugdahl & Davidson, 2003). In principle, the two cerebral hemispheres control basic movements and sensations of the body in a crossed manner, which means that the left hemisphere controls the right side of the body and vice versa (Thompson, 2000). However, the left and right hemispheres are not equivalent in every respect and basic asymmetries in their capabilities and organization have been found (Springer & Deutsch, 1998). Based on observations of neurological case studies, Broca (1865) provided the first solid evidence of hemispheric asymmetry for language.

The corpus callosum is considered to play an important role in language lateralisation. It is composed of myelinated nerve fibers (white matter) containing no neuronal cell bodies, and it is the largest transverse connection between the left and right hemisphere (Webb & Adler, 2008). According to Rohkamm (2003), the two hemispheres are linked by the corpus callosum and its disconnection results in the so called ‘split brain syndrome’. Split brain subjects display hemispheric asymmetry for language modalities, which suggests corpus callosum involvement in the process of relaying language between the two hemispheres (Gazzaniga, 2000; Penfield & Roberts, 1959). On the basis of split brain studies, it has been confirmed that the major neural mechanisms for language are localised in the more analytical left hemisphere, while non-linguistic functions (e.g., perceptual and spatial processes) are localised in the more holistic right hemisphere (Springer & Deutsch, 1998; Webb & Adler, 2008).

Van Der Knaap and Van Der Ham (2011) stated that anatomical and functional lateralisation can be explained by either an inhibitory or excitatory model of callosal function. The inhibitory model presumes that the corpus callosum serves primarily inhibitory functions in order to maintain independent processing in the two hemispheres and to keep them separate (Cook, 1984; Kinsbourne, 1982). Thus, inhibition of the non-specialized hemisphere occurs, while the specialized hemisphere engages in a task. The excitatory model presumes that the corpus callosum serves an excitatory function that supports bilateral hemispheric activation and transmission of information, resulting in the activation of the unspecialized hemisphere (Galaburda, Rosen, & Sherman, 1990). Therefore, the excitatory theory predicts that increased connectivity, in the form of a larger corpus callosum, would be associated with a decrease in asymmetry, whereas the inhibitory theory predicts that increased connectivity would be associated with an increase in asymmetry.

2.4.2 Neuroimaging Tests versus Behavioural Tests

The most direct way to assess differences between the two hemispheres is to measure the activity and structure of the brain with neuroimaging tests. These tests are applied to draw inferences from evoked patterns of cortical activity about the functional anatomy of the brain, i.e., they measure brain activity (Watkins & Klein, 2011). Neuroimaging tests can be divided into several categories and the distinction between functional and structural neuroimaging tests is considered to be the most fundamental (Springer & Deutsch, 1998). According to Webb and Adler (2008), structural neuroimaging refers to tests that provide views of cross sections of the brain and show brain structure or anatomy, such as computerized tomography (CT) or magnetic resonance imaging (MRI) scans.

Functional neuroimaging refers to tests that provide views of some particular aspect of brain activity (e.g., cerebral blood flow, glucose metabolism, and oxygen level), such as single photon emission computed tomography (SPECT), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI) scans (Webb & Adler, 2008). These tests are sensitive to different signals. SPECT and PET scanning involves the injection of contrast substances into the bloodstream and, depending on the contrast substance injected, show the brain areas with increased blood flow or a change in glucose or neurotransmitter metabolism (Webb & Adler, 2008). fMRI requires no contrast injection but uses intrinsic changes in the level of oxygen in the blood to measure brain activity (Watkins & Klein, 2011). In addition, electroencephalography (EEG), magnetoencephalography (MEG), and functional near-infrared spectroscopy (fNIRS) are three other methods of measuring brain function (Ferrari & Quaresima, 2012; Keil et al., 2014). According to Keil et al. (2014) EEG is an electrophysiological measure that records electrical activity of the brain along the scalp, whereas MEG records magnetic fields associated with brain activity. In contrast, fNIRS detects changes in brain activity through hemodynamic responses using near-infrared light (Ferrari & Quaresima, 2012).

There are also behavioural techniques available to study asymmetries in brain function. These tests take advantage of the natural split of the brain into left and right hemispheres. Various behavioural studies on language lateralisation have used dichotic listening, visual hemifield, and dual-task paradigms to assess hemispheric involvement. Each of these techniques depend on the involvement of both hemispheres to assess brain dominance. All three paradigms are suitable to investigate cerebral language dominance provided they are administered properly (Hellige & Sergent, 1986; Hunter & Brysbaert, 2008; Kosaka, Hiscock, Strauss, Wada, & Purves, 1993; Voyer, 1998).

2.4.3 Dichotic Listening Paradigm

Dichotic listening refers to the simultaneous binaural presentation of two contrasting acoustic stimuli (see Figure 1a); thus, one auditory stimulus is presented to the left ear while another one is presented to the right ear (Hugdahl, Westerhausen, Alho, Medvedev, & Hamalainen, 2008; Westerhausen & Hugdahl, 2008). Dichotic listening is a technique utilized to evaluate functional cerebral hemispheric asymmetry for the processing of auditory speech stimuli (Bryden, 1988; Hugdahl, 2003). According to Rimol, Eichele, and Hugdahl (2006), the purpose of dichotic listening is to provide more information than can be consciously analysed at all times in order to create an overload of the perceptual system. Verbal stimuli, such as word rhymes (e.g., /house/-/mouse/) or consonant-vowel (CV) syllables (e.g., /ga/-/ba/) with the same voicing, have been most frequently used to study hemispheric asymmetry for speech sound processing (Westerhausen & Hugdahl, 2008). A consistent finding in the presentation of linguistic stimuli is a ‘right ear advantage’ (REA) (Kimura, 1961; Rimol et al., 2006). This reflects predominant reports that the syllables presented to the right ear are more readily perceived than syllables presented to the left ear (Hiscock, Cole, Benthall, Carlson, & Ricketts, 2000; Hugdahl, Helland, Faerevaag, Lyssand, & Asbjornsen, 1995). On the other hand, a ‘left ear advantage’ (LEA) has been found for nonverbal stimuli (e.g., melodies) simultaneously presented to both ears (Kimura, 1964). The routing of auditory information is illustrated in Figure 1b.

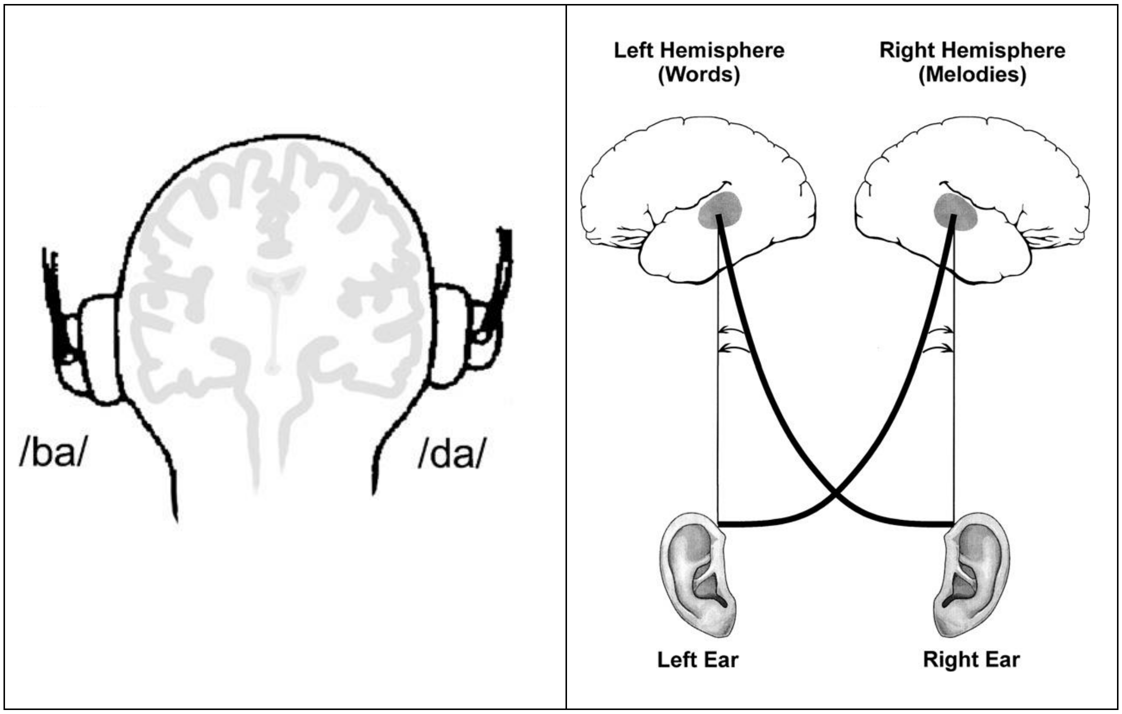

Figure 1. Illustration of the dichotic listening paradigm (Westerhausen & Hugdahl, 2008) (left panel), and the routing of the auditory pathway from the external ear to the auditory cortex of each hemisphere (Kimura, 2011) (right panel).

Dichotic Listening Models

There are a number of explanations for the REA in the processing of information for binaurally presented verbal stimuli (Asbjornsen & Hugdahl, 1995; Kimura, 1961; Kinsbourne, 1970). Two popular models of dichotic listening are the structural model and the attentional model. Both models refer to the functional integrity of the corpus callosum. According to Westerhausen and Hugdahl (2008), the ability to direct attention to one ear is mediated by callosal fibers. Therefore, the corpus callosum can be viewed as a channel for the automatic exchange of information between the two cerebral hemispheres, as well as a channel that enables a dynamic and flexible interaction (Westerhausen & Hugdahl, 2008; Westerhausen et al., 2006). Thus, both the stimulus-driven bottom-up transfer and the attentional top-down modulation in stimulus processing, such as on dichotic listening tasks, are supported by the corpus callosum.

Kimura (1961) postulated the structural model in which the REA is considered to reflect the asymmetric ascending input of auditory information from the temporal cortex. That is, the auditory input from the right ear is projected to the temporal cortex of both the contralateral and ipsilateral cerebral hemisphere. The ipsilateral hemisphere is assumed to be inhibited during dichotic listening, so that only speech stimuli presented to the right ear are immediately transmitted to the language areas in the left hemisphere. However, the left ear input, initially transferred to the right hemisphere, needs to pass through the corpus callosum before it reaches the language specialised left hemisphere. Therefore, the structural model is based on the interaction of the two cerebral hemispheres via the corpus callosum and the dominance of the left hemisphere for language processing. This right-ear bias, indicating a left hemisphere advantage for the processing of verbal stimuli, is often referred to as ‘bottom-up’ processing (Westerhausen & Hugdahl, 2008).

Kinsbourne (1970) proposed a model that considers the role of attention in dichotic listening tasks. Each hemisphere primarily attends to the contralateral ear and the anticipation of incoming verbal stimuli is thought to activate the left hemisphere, preparing for subsequent processing. The left hemisphere activation occurs automatically and results in an attentional bias towards the contralateral right ear. As a consequence, acoustic information from the right ear is processed faster and more often reported. Deliberating directing attention to the right ear typically increases the REA, whereas directing attention to the left ear may decrease the REA or result in a LEA. The process of anticipation, where the left hemisphere awaits verbal stimuli, is often referred to as ‘top-down’ processing (Westerhausen & Hugdahl, 2008).

Interaural Intensity Differences

The effect of the manipulation of the loudness of CV syllables, simultaneously presented to both ears, during a dichotic listening paradigm has been investigated. This alteration in sound level is known as the interaural intensity difference (IID). Studies have investigated whether changes in the IID would also have an impact on the magnitude of the REA (Hugdahl et al., 2008; Tallus, Hugdahl, Alho, Medvedev, & Hamalainen, 2007). Hugdahl et al. (2008) examined dichotic listening in an undirected test by altering the IID between the left and right ear. In total, 33 right-handed participants were tested on a CV dichotic listening task. The IID was gradually varied in steps of 3 dB from -21 dB in favour of the left ear and +21 dB in favour of the right ear. For the baseline condition at 0 dB, as expected, a REA was evident. When the IID was modulated to favour the right ear, a clear REA was present. However, when the IID was modulated to favour the left ear, the REA persisted until the stimuli were 9 dB more intense in the left ear. Therefore, it was concluded that the REA withstands an IID of -9 dB before shifting to a LEA.

2.4.3.1 Dichotic Listening in Stuttering

There have been a large number of studies examining dichotic listening in PWS and the results of these studies have been mixed (Blood, 1985; Blood, Blood, & Hood, 1987; Cimorell-Strong, Gilbert, & Frick, 1983; Cross, 1987; Foundas, Hurley, & Browning, 1999; Gruber & Powell, 1974; Liebetrau & Daly, 1981; Newton, Blood, & Blood, 1986; Pinsky & McAdam, 1980; Slorach & Noehr, 1973; Sommers, Brady, & Moore, 1975). However, several researchers have proposed that AWS show differences in the magnitude of the REA or a LEA on dichotic listening tasks (Blood & Blood, 1989a; Brady & Berson, 1975; Curry & Gregory, 1969; Foundas et al., 2004; Robb, Lynn, & O'Beirne, 2013; Rosenfield & Goodglass, 1980). For example, Blood and Blood (1989a) investigated hemispheric asymmetry in 18 male and 18 female AWS on a verbal dichotic listening paradigm and compared them to 36 AWNS. Both participant groups demonstrated a REA. However, a significant difference was found between the entire group of AWS and AWNS in the magnitude of ear advantage, with AWNS showing a stronger REA.

Foundas, Corey, Hurley, and Heilman (2004) assessed 18 left- and right-handed AWS and 28 AWNS on a verbal dichotic listening paradigm in three attention conditions, including non-directed attention, right-directed attention and left-directed attention. The investigation revealed that all of the AWNS and right-handed male AWS presented with a REA in the non-directed attention condition. On the contrary, the left-handed male AWS presented with a LEA (i.e., more right hemisphere processing), and the right-handed female AWS presented with no lateral ear bias in the non-directed attention condition. For the entire group of AWS, handedness was significantly related to the percentage of left and right ear responses and the lateralisation shift magnitude, an outcome that did not apply to the AWNS participants.

Robb, Lynn, and O’Beirne (2013) examined undirected and directed dichotic listening with CV stimuli in seven AWS and seven sex and age matched AWNS. For the undirected task, a manipulation of the IID of the CV stimuli presented to the left and right ear was involved. The results for the undirected task revealed a REA for both AWS, as well as AWNS. However, the two participant groups differed in terms of the IID point at which a previous REA became a LEA. The cross-over point was found to occur earlier for AWS, which indicated stronger right hemispheric contribution for speech processing compared to their controls. For the directed attention task, an equal intensity for the CV stimuli was used and no differences were found between AWS and AWNS.

2.4.3.2 Dichotic Listening in Bilingualism

The relationship between dichotic listening and bilingualism has been examined over the past decades (Albanese, 1985; Fabbro, Gran, & Gran, 1991; Gordon & Zatorre, 1981; Gresele, Garcia, Torres, Santos, & Costa, 2013; Ke, 1992; Morton, Smith, Diffey, & Diubaldo, 1998; Nachshon, 1986; Persinger, Chellew-Belanger, & Tiller, 2002; Starck, Genesee, Lambert, & Seitz, 1977; Wesche & Schneiderman, 1982). Typically, sequential bilinguals have been found to show a REA on dichotic listening tasks (D'Anselmo, Reiterer, Zuccarini, Tommasi, & Brancucci, 2013; Ip & Hoosain, 1993; Soveri, Laine, Hamalainen, & Hugdahl, 2011). Furthermore, meta-analyses have suggested that left hemisphere dominance for language might be greater for sequential bilinguals compared to monolinguals (Hull & Vaid, 2006, 2007). For example, Ip and Hoosain (1993) assessed dichotic listening of Chinese and English words in 18 sequential bilinguals (Chinese L1, English L2). A strong REA was found for both languages, indicating left hemisphere dominance.

Soveri, Laine, Hamalainen, and Hugdahl (2011) examined undirected and directed attention dichotic listening in right-handed Finnish monolinguals and simultaneous bilinguals (Finnish and Swedish) from two age groups, composed of 30 to 50 year-olds (18 monolinguals, 17 bilinguals) and 60 to 74 year-olds (14 monolinguals, 16 bilinguals). In the undirected condition, all four groups were found to demonstrated a REA. In the directed attention task, the bilingual participants demonstrated more correct responses for both the forced-left and forced-right condition. That is, bilinguals showed an advantage in (a) directing attention and (b) inhibiting irrelevant information compared to monolinguals, regardless of left or right ear input.

D'Anselmo, Reiterer, Zuccarini, Tommasi, and Brancucci (2013) assessed 30 native German speakers and 30 native Italian speakers, whose second language was English. The dichotic listening task included words in both L1 and L2 to examine the effects of similarity between languages on hemispheric asymmetry in bilinguals. Although results revealed a significant REA for the number of responses in both languages and in both groups, the REA for English language processing was stronger for the German group, indicating a greater left hemisphere contribution for native German speakers. It was concluded that linguistic similarity of languages spoken by bilingual individuals is an important factor when assessing dichotic listening.

2.4.3.3 Summary of Dichotic Listening Paradigm

Most people demonstrate a REA for the processing of linguistic information. This effect is found for both directed and undirected dichotic listening tasks, which indicates greater left hemisphere processing. However, there is evidence that suggests the REA is less pronounced in PWS. Moreover, a LEA (greater right hemisphere processing) has also been observed in PWS compared to PWNS. Among bilinguals, a REA is typically found on dichotic listening tasks. Bilinguals also perform at a higher level than monolingual speakers on directed attention conditions. Collectively, it appears that both PWS and bilinguals exhibit a tendency to present with a REA similar to PWNS and monolinguals. However, it appears that the magnitude of the REA is less robust in PWS. In contrast, sequential bilinguals appear to show a strong REA on dichotic listening tasks. At present, there are no dichotic listening studies that have investigated BWS. Assessing and comparing BWS to MWS, as well as BWNS might contribute to a better understanding of the role of cerebral hemispheric dominance in PWS and bilingualism.

2.4.4 Visual Hemifield Paradigm

While dichotic listening paradigms enable researchers to use auditory stimuli to study cerebral hemispheric asymmetry, a non-invasive procedure known as visual hemifield testing allows researchers to study similarities and differences of how the two hemispheres process visual information. A brief stimulus is presented either to the left or right of a central point at which the participant is fixating. In this way, stimuli can be lateralised and presented to primarily one hemisphere (Springer & Deutsch, 1998). Due to the crossing of nasal fibers in the optic chiasm, visual stimuli flashed in the left visual hemifield (LVF) project initially to the right cerebral hemisphere, and visual stimuli flashed in the right visual hemifield (RVF) project initially to the left cerebral hemisphere (Beaumont, 1983). This phenomenon is based on the fact that the optical projections from the retina to the visual cortex are arranged in such a manner that the light falling onto the nasal region of the retina of both eyes will project the stimuli contralaterally (Hellige, Laeng, & Michimata, 2010; Hugdahl, 2013). In contrast, light falling on the lateral region of the retina will project ipsilaterally, provided that the participant is fixating on a point in the middle of the visual field. The routing of visual information is illustrated in Figure 2a, and an example of a visual hemifield testing environment is given in Figure 2b. A series of studies by Boles (1987, 1990, 1994) found that bilateral presentations of stimuli result in even larger asymmetry than unilateral presentations. In general, investigations suggest that about 75-80% of right-handed individuals present with a RVF advantage for the identification of language related stimuli, which corresponds to the REA in dichotic listening (Bruder, 1995; Springer & Deutsch, 1998). In contrast, a LVF advantage has been found for nonverbal visual stimuli such as faces (Springer & Deutsch, 1998; Yovel, Levy, Grabowecky, & Paller, 2003).

Fixation Control and Backward Masking

In visual hemifield testings, the visual stimulus is presented at a specified distance from a central fixation point. Therefore, it is important to control fixation during stimulus presentation to ensure that it is presented in the correct portion of the visual field in order to be processed appropriately. Bourne (2006) found that direct central fixation methods, monitoring eye movements, and controlling test stimulus presentation were most effective methods for fixation control. One way to monitor adequate fixation is to flash, together with the information presented in the LVF and/or RVF, a left- or rightwards pointing arrow at the fixation location that indicates the stimulus that is required to be named (Hunter & Brysbaert, 2008). This way, attention is directed towards the fixation location at the beginning of a trial.

One further control is backward masking, which refers to a reduction in the visibility of an object. This form of masking is performed by the immediate presentation of a second object, i.e., masking stimuli preceding and following the target stimuli (Enns & Di Lollo, 2000). According to Enns and Di Lollo (2000), utilizing backward visual masking ensures that the exposure duration is controlled and that after-image effects are prevented.

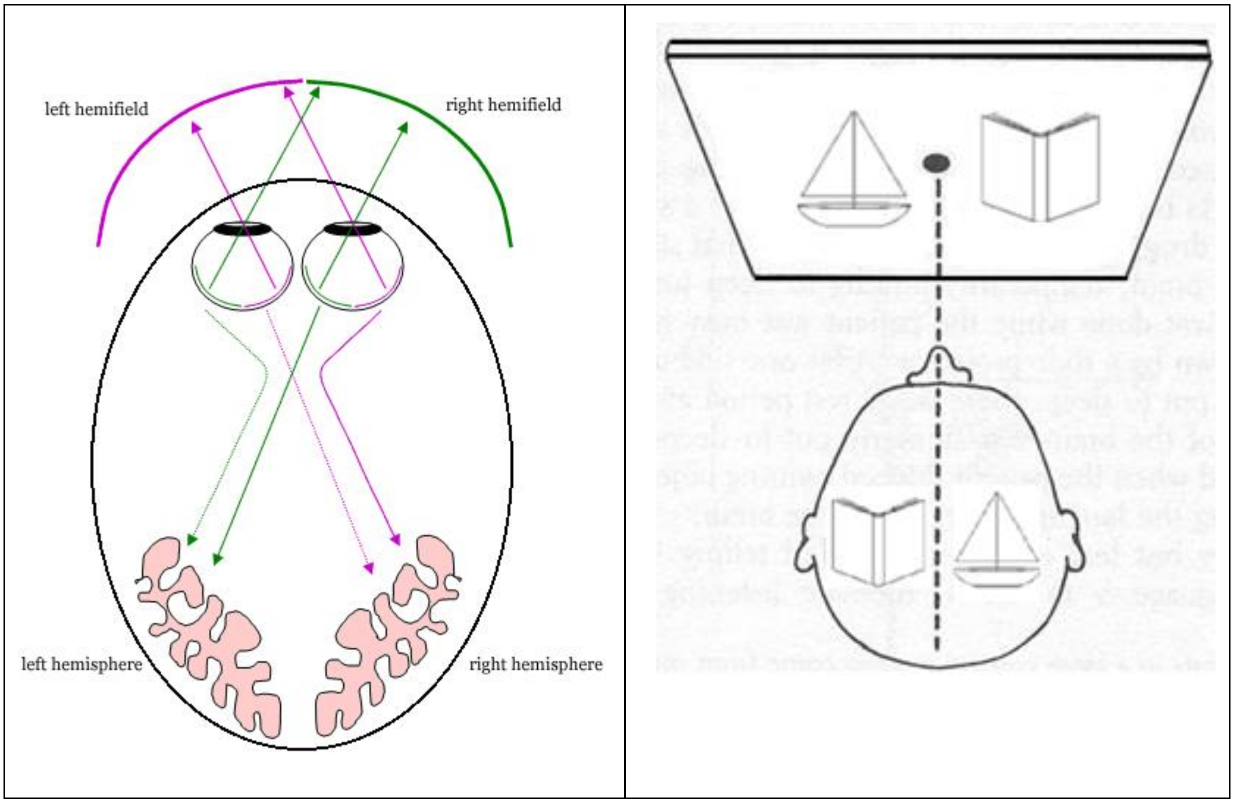

Figure 2. Illustration of the routing of visual information according to visual field (left panel). Retrieved from http://opl.apa.org/experiments/about/aboutwordrecognition.aspx. Illustration of an example of a visual hemifield testing paradigm (right panel). Adapted from http://journal.frontiersin.org/article/10.3389/fnhum.2015.00158/full.

2.4.4.1 Visual Hemifield in Stuttering

A large number of researchers have investigated visual hemifield in PWS and the results of these studies have been inconsistent (Hardin, Pindzola, & Haynes, 1992; Rami, Shine, & Rastatter, 2000; Rastatter & Dell, 1987a, 1988; Rastatter & Loren, 1988; Rastatter, Loren, & Colcord, 1987; Rastatter & Stuart, 1995; Szelag et al., 1993; Szelag, Herman-Jeglinska, & Garwarska-Kolek, 1997). However, several studies have proposed a LVF advantage for AWS on visual hemifield tasks (Hand & Haynes, 1983; Johannsen & Victor, 1986; Moore, 1976; Rastatter & Dell, 1987b; Rastatter, McGuire, & Loren, 1988). For example, findings by Moore (1976) indicated greater right hemisphere dominance for language in AWS compared to AWNS.

Hand and Haynes (1983) compared 10 male AWS to 10 matched AWMS on a lexical decision task. The task included word and non-word stimuli, which were tachistoscopically presented to the LVF and RVF. Both vocal and manual reaction times were collected to examine the hemispheric contribution in linguistic information processing, as well as to determine differences between the two response modes. It was found that the AWS presented with a LVF advantage, i.e., more right hemisphere involvement. Furthermore, the AWS group demonstrated slower reaction times for both vocal and manual responses than AWNS group.

Rastatter and Dell (1987b) examined cerebral dominance and language processing for visual stimuli in 14 AWS (7 males, 7 females) and compared them to 14 matched AWNS. All participants were assessed on a lexical decision task with unilateral tachistoscopically presented abstract and concrete words, in which vocal reaction times were obtained. For both groups, the results indicated superior processing of concrete words in the right hemisphere and superior processing of abstract words in the left hemisphere. However, the AWS displayed slower reaction times than AWNS in most of the testing conditions. Furthermore, the results revealed significantly slower reaction times of the left compared to the right hemisphere in AWS. That is, the right hemisphere processed the concrete stimuli more efficiently than the left hemisphere processed the abstract stimuli.

2.4.4.2 Visual Hemifield in Bilingualism

There have been a large number of studies examining visual hemifield in bilingualism (Adamson & Hellige, 2006; Bentin, 1981; Endo, Shimizu, & Nakamura, 1981; Evans, Workman, Mayer, & Crowley, 2002; Hausmann, Durmusoglu, Yazgan, & Gunturkun, 2004; Hoosain & Shiu, 1989; Ibrahim, 2009; Ibrahim & Eviatar, 2009; Ibrahim, Israeli, & Eviatar, 2010; Jonczyk, 2015; Joss & Virtue, 2010; Karapetsas & Andreou, 2001; Sewell & Panou, 1983; Shanon, 1982; Silverberg, Bentin, Gaziel, Obler, & Albert, 1979; Vaid & Frenck-Mestre, 2002; Wuerger et al., 2012; Wuillemin, Richardson, & Lynch, 1994). Typically, sequential bilinguals have been found to show a strong RVF advantage on visual hemifield tasks (Beaton, Suller, & Workman, 2007; Hull & Vaid, 2006, 2007; Lam & Hsiao, 2014; Peng & Wang, 2011; Vaid, 1987; Workman, Brookman, Mayer, Rees, & Bellin, 2000).

A tachistoscopic study conducted by Vaid (1987) examined 16 monolingual, 16 simultaneous bilingual (English and French), and 16 sequential bilingual adults (8 English L1 and French L2, 8 French L1 and English L2) in rhyme and syntactic category matching conditions. In the rhyme condition, participants were first auditorily exposed to a target word while fixating on the centre of the screen, and then presented with a visual stimulus in the form of a word to either the LVF or RVF for 100 ms. Subsequently, they were asked to judge for rhyming by pressing response keys. In the syntactic category condition, participants heard a target word while fixating on the centre of the screen, followed by the same word presented in a sentence. Subsequently, a visual stimulus in the form of a test word was flashed in the LVF or RVF. The participants were asked to judge if the auditorily and visually presented words were from the same word classes (e.g., nouns, verbs, adjectives). All three groups demonstrated RVF superiority (greater left hemispheric processing) for both verbal judgment tasks. This finding was even more pronounced in sequential bilinguals than in simultaneous bilinguals or monolinguals.

Beaton, Suller and Workman (2007) investigated hemispheric asymmetry for single word recognition in 14 monolingual (English) and 44 proficient bilingual right-handed adults, of which 25 were simultaneous (English and Welsh) and 19 were sequential (10 English L1 and Welsh L2, 9 Welsh L1 and English L2) bilinguals. The visual stimuli consisted of 40 high frequency Welsh words and their English translation (80 words in total). The monolingual group was only tested in the English language, whereas the bilinguals were tested in both languages. During the assessment, participants were asked to fixate on the centre of the screen and report back on the single words flashed either to the LVF or RVF. Each stimulus was presented for 150 ms. A RVF advantage (greater left hemispheric processing) was obtained for both groups and languages. However, for the bilingual group, the RVF advantage was more pronounced for Welsh words than for English words regardless of the age of second language acquisition.

Peng and Wang (2011) applied a Stroop paradigm, using visual stimuli in the form of Chinese single characters, to study hemisphere lateralisation in 14 right-handed sequential bilinguals (Chinese L1, English L2). Two conflicting stimuli (word and colour) were presented simultaneously on a screen for 150 ms to either the LVF or RVF, with the name of one colour appearing in the ink of another colour. During the testing, participants were either asked to respond by pressing one out of four colour patch labelled buttons, or to give a verbal response to identify the stimuli. The Stroop effect was found to be strongest for the stimuli presented to the RVF, which indicates greater left hemispheric language processing in the sequential bilingual participants. Furthermore, the Stroop effect was reported to be stronger for the verbal responses than for the manual responses.

2.4.4.3 Summary of Visual Hemifield Paradigm

Overall, the results of visual hemifield studies in the field of stuttering indicate atypical hemispheric language processing in PWS. That is, they have been found to show a LVF advantage, which indicates right hemispheric processing. Among bilinguals, there seems to be consensus that sequential bilinguals present with a RVF advantage for linguistic stimuli, which indicates greater left hemispheric language processing. Interestingly, sequential bilinguals have been found to exhibit greater left hemisphere involvement compared to simultaneous bilinguals, as well as monolinguals. Collectively, PWS and sequential bilinguals appear to show divergent patterns of language processing. However, at present, there are no visual hemifield studies that have investigated BWS.

2.4.5 Dual-Task Paradigm

Dual-task paradigms have been used to study functional cerebral specialisation for cognitive, perceptual, and motor behaviours (Kinsbourne & Hiscock, 1983). The dual-task paradigm, such as the verbal-manual interference task, is a production-based paradigm and reflects hemispheric involvement through decreased motor performance (Hull & Vaid, 2007). An illustration of a verbal-manual interference task is provided in Figure 3. According to Kinsbourne and Hiscock (1983), the language dominant left hemisphere is required to simultaneously control speech and perform movements of the contralateral hand efficiently. An asymmetrical decrease in finger-tapping performance for the right hand indicates a lack of processing resources of the left cerebral hemisphere. That is, it is presumed that greater right-hand interference, in the form of slower finger-tapping, reflects greater left hemisphere involvement. The interference occurs since hand and finger movements are primarily controlled by the contralateral cerebral hemisphere (Hellige & Kee, 1990; Kinsbourne & Hiscock, 1983). Kahneman (1973) called this kind of interference 'capacity interference', and Norman and Bobrow (1975) hypothesised that it reflects limitations on the availability of cognitive processing capacity, resources, or attention.

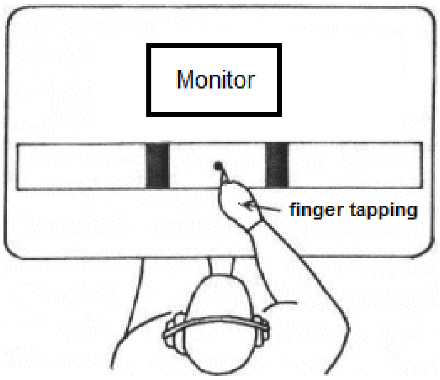

Figure 3. Example of a dual-task paradigm. In this example, the participant is required to orally read text presented on a computer monitor while simultaneously tapping with the right hand. Adapted from http://www.yorku.ca/mack/mackenzie_chapter.html.

Role of Working Memory

A prerequisite of dual-task performance is to not only successfully divide attention between two activities, but also to maintain task relevant information. On this account, working memory is considered to play an important role in the performance of dual-tasks. According to Baddeley (2010), working memory is concerned with the temporary storage and manipulation of information while engaging in cognitively challenging tasks. Bajaj (2007) reviewed the potential relationship between working memory and stuttering and pointed out that PWS demonstrate decreased performance on some dual-tasks compared to fluent speakers. In contrast, bilinguals appear to perform better on dual-tasks, particularly visual ones, than monolinguals (Bialystok, 2011a; Bialystok, Craik, & Ruocco, 2006). There is considerable evidence that bilingual speakers have enhanced executive control (i.e., attention control system for complex cognitive tasks) (Bialystok, 2011b), and that both languages are always active to some degree (Rodriguez-

Fornells et al., 2002; Thierry & Wu, 2007). Thus, with both languages active, bilinguals are required not only to focus their attention to the target language while inhibiting attention to the other language, but also to monitor the context in order to switch attention when the other language is needed (Bialystok, 2011a). Hence, central executive functions are constantly needed since bilingualism itself creates a dual-task situation.

2.4.5.1 Dual-Task in Stuttering

Dual-task performance in PWS has been examined by a number of researchers (Bosshardt, 1999, 2002; Bosshardt, Ballmer, & De Nil, 2002; Forster & Webster, 1991; Metten et al., 2011; Saltuklaroglu, Teulings, & Robbins, 2009; Song, Peng, & Ning, 2010). In general, PWS have been found to be more vulnerable to interference from concurrent tasks and they perform poorer compared to PWNS (Jones, Fox, & Jacewicz, 2012; Smits-Bandstra, De Nil, & Rochon, 2006; Smits-Bandstra & De Nil, 2009). On verbal-manual interference tasks, AWS typically show greater finger-tapping disruption for both hands compared to AWNS (Greiner, Fitzgerald, & Cooke, 1986; Sussman, 1982). The pattern found for AWS has also been found in CWS compared to CWNS (Brutten & Trotter, 1986). However, according to Brutten and Trotter (1985), verbal-manual interference in CWS is greater for left-hand tapping compared to right-hand tapping.

Sussman (1982) examined dual-task performance in right-handed AWS (8 males, 2 females), and left-handed (3 males, 7 females) and right-handed (4 males, 6 females) AWNS. Concurrent finger-tapping was used during visual tasks (imagine and track alphabet shapes, chimeric figure test) and verbal tasks (reading aloud, counting backwards). A right-hand tapping disruption during concurrent verbal tasks was only found in the right-handed AWNS. All of the AWS and left-handed AWNS demonstrated right- and left-hand tapping disruptions, suggesting symmetrical patterns of hemispheric language interference. In general, AWS demonstrated a greater disruption in finger-tapping during the verbal tasks, indicative of left and right hemisphere interference, than the left- and right-handed AWNS.

Greiner, Fitzgerald and Cooke (1986) investigated hemispheric functioning in right-handed (15) and left-handed (5) male AWS and matched AWNS. The participants were asked to perform four experimental tasks including finger-tapping alone, finger-tapping and spontaneous speech, finger-tapping and reading, and finger-tapping and singing. Each task was performed for 120s and consisted of eight trials. The tapping hand was alternated after each trial. The AWS group exhibited more dual-task interference for both hands (left and right hemisphere interference) in the form of slower tapping rates while speaking simultaneously compared to the controls.

2.4.5.2 Dual-Task in Bilingualism

A number of researchers have examined dual-task performance in bilingualism and the results have been mixed (Bialystok, 2011a; Fabbro, Gran, Basso, & Bava, 1990; Green, 1986; Green, Nicholson, Vaid, White, & Steiner, 1990; Sandoval, Gollan, Ferreira, & Salmon, 2010; Singh, 1990; Vaid, 2001). However, on verbal-manual interference tasks, sequential bilinguals have been found to typically show greater finger-tapping disruption for the right hand (Badzakova-Trajkov, Kirk, & Waldie, 2008; Furtado & Webster, 1991; Hall & Lambert, 1988; Hoosain & Shiu, 1989; Hull & Vaid, 2006, 2007; Soares, 1984). For example, Hall and Lambert (1988) compared 48 male right-handed sequential bilinguals (English L1, French L2) across different proficiency levels of L2. All participants were tested on two linguistic tasks (reading aloud, identifying pictures of common objects) during concurrent finger-tapping. No significant group differences in hemispheric processing were found between the groups. All groups across different proficiency levels showed significantly greater disruption during right-hand tapping, thus, greater left hemisphere interference.

Soares (1984) compared 16 male right-handed sequential bilinguals (Portuguese L1, English L2) with 16 matched monolinguals (English) on a series of concurrent activities. All of the participants performed concurrent finger-tapping during five tasks (talking, reading aloud, silent reading, reciting automatisms, thinking). The monolinguals performed only one set of tasks in English, whereas the bilinguals performed two sets of tasks (English, Portuguese). The results revealed more interference in finger-tapping with the right hand during verbal tasks for both the bilingual and monolingual groups, which was indicative of greater left hemisphere involvement. No difference in lateralisation was found between the bilingual and monolingual participants or the two languages of the sequential bilinguals.

Furtado and Webster (1991) examined 16 right-handed simultaneous bilinguals (English and French), 32 right-handed sequential bilinguals (16 English L1 and French L2, 16 French L1 and English L2), and 16 right-handed English monolinguals. Each group was comprised of an equal number of males and females. All participants were asked to perform concurrent finger-tapping during a reading task and a translation task. The outcome indicated a language specific effect in lateralisation patterns, irrespective of whether the first language was French or English. In other words, bilingual participants displayed only left hemisphere language interference for English, but both left and right hemispheric language interference for French. It was hypothesised that this language-specific effect might be due to phonetic differences between the English and French language (e.g., prosody), ultimately leading to a differential activation of the hemispheres for processing the two languages. Furthermore, it was noted that the language-specific effect might also reflect some of the social psychological dynamics of the interaction between the participants and researcher since all the instructions were given in English.

Badzakova-Trajkov, Kirk, and Waldie (2008) examined sequential proficient bilinguals (Macedonian L1, English L2) with a dual-task paradigm. The groups consisted of 14 bilinguals (8 males, 6 females) and 16 monolinguals (10 males, 6 females), who were right-handed and matched on sex and chronological age. A total of six tasks were used during the testing, consisting of left finger-tapping and right finger-tapping alone, and left finger-tapping, as well as right finger-tapping, during reading of narrative passages (reading aloud, silent reading). Both monolinguals and bilinguals displayed more right- than left-hand interference during the dual-tasks, indicating greater left lateralised speech. However, the bilingual group demonstrated more left-hand interference in both languages compared to the monolingual group.

2.4.5.3 Summary of Dual-Task Paradigm

In general, PWS show more verbal-manual interference on dual-task paradigms than PWNS, characterised by slower finger-tapping rates for both hands during verbal tasks. That is, both hemispheres appear to be involved. On the other hand, sequential bilinguals have been found to generally demonstrate greater finger-tapping disruption for the right hand, suggesting more left hemisphere interference during dual-task performance. At present, there are no dual-task studies that have investigated BWS.

2.5 Summary

2.5.1 Developmental Stuttering

Past findings for PWS on the three behavioural tests of hemispheric asymmetry indicate a difference in cerebral lateralisation between PWS and PWNS. On dichotic listening paradigms, a range of results have been found comparing PWS to PWNS (Blood, 1985; Blood et al., 1987; Cimorell-Strong et al., 1983; Cross, 1987; Foundas et al., 1999; Gruber & Powell, 1974; Liebetrau & Daly, 1981; Newton et al., 1986; Pinsky & McAdam, 1980; Slorach & Noehr, 1973; Sommers et al., 1975). There is general agreement that most PWS show a REA (left hemisphere) for language processing (Blood, 1985; Blood & Blood, 1989a; Brady & Berson, 1975; Foundas et al., 2004; Robb et al., 2013; Rosenfield & Goodglass, 1980). However, the magnitude of the REA has been found to differ between PWS and PWNS (Blood & Blood, 1989a; Robb et al., 2013). PWS are more likely to show a LEA under IID conditions compared to PWNS. For the visual hemifield paradigm, results indicate a greater LVF (right hemisphere) preference for language processing among PWS (Hand & Haynes, 1983; Johannsen & Victor, 1986; Moore, 1976; Rastatter & Dell, 1987b; Rastatter et al., 1988; Szelag et al., 1993). With respect to the dual-task paradigm, PWS generally demonstrate more interference than PWNS in the form of slower finger-tapping rates for both hands, indicating divergent patterns of cerebral language lateralisation (Brutten & Trotter, 1985, 1986; Greiner et al., 1986; Sussman, 1982). To date, the results obtained for PWS on the various behavioural tests of hemispheric asymmetry have focused on monolingual speakers.

2.5.2 Bilingualism

Past findings for bilinguals on the three behavioural tests of hemispheric asymmetry seem to yield an inconsistent profile. This might be due to the wide variability in defining simultaneous/sequential bilingualism and proficient/non-proficient bilinguals. Furthermore, the experimental design varies across studies, which may further contribute to disparate results among studies. However, a number of studies have suggested that sequential bilinguals show a REA on dichotic listening tasks (D'Anselmo et al., 2013; Ip & Hoosain, 1993; Soveri et al., 2011), a strong RVF advantage on visual hemifield tasks (Beaton et al., 2007; Peng & Wang, 2011; Workman et al., 2000), and greater finger-tapping disruption for the right hand on dual-tasks (Badzakova-Trajkov et al., 2008; Furtado & Webster, 1991; Soares, 1984). Hull and Vaid (2006) conducted a meta-analysis on studies that examined functional hemispheric asymmetry in monolingual and bilingual adults using dichotic listening, visual hemifield, and dual-task paradigms. Overall, the meta-analysis revealed that monolinguals and sequential bilinguals were left hemisphere dominant, whereas simultaneous bilinguals demonstrated greater bilateral hemispheric involvement. These findings were later supported by Hull and Vaid (2007) indicating that sequential bilinguals show greater left hemisphere reliance than simultaneous bilinguals or monolinguals.

2.5.3 Conclusion

In summary, the literature on both stuttering and bilingualism varies with respect to the number of participants, age of participants, languages involved, language proficiency, age of language acquisition, as well as the methodologies used in assessing stuttering and bilingualism. Although the relationship between stuttering and bilingualism has been receiving increasing interest, most of this research has focused on describing the perceptual and productive features of stuttering moments. Missing from the current literature are studies examining the role of the brain in BWS. Interestingly, both PWS and sequential bilinguals seem to show some divergent patterns of language lateralisation. A consistent finding in most studies has been that PWS, compared to PWNS, demonstrate a strong tendency toward bilateral or right hemisphere cortical dominance during language tasks. In contrast, sequential bilinguals tend to show a strong tendency towards left hemisphere dominance compared to simultaneous bilinguals and monolinguals. The past finding of a spread of cerebral activation among PWS and a reliance of left hemisphere activation among sequential bilinguals presents an interesting paradox in regard to the BWS. Would the language lateralisation of a BWS be more reflective of a BWNS or a MWS? Therefore, neuroimaging and behavioural studies investigating BWS compared to MWS, as well as their non-stuttering controls, may provide new and important insight not only into the disorder of stuttering but also into the phenomenon of bilingualism.

2.6 Statement of Problem

Based on behavioural tests of cerebral hemispheric asymmetry, data are emerging on the effects of stuttering, as well as bilingualism, on the processing and production of language. Previous research has provided evidence that both stuttering and bilingualism activate multiple cortical regions and that PWS, as well as sequential bilinguals, show divergent patterns of cerebral lateralisation during language processing and production. Hemispheric asymmetries have been studied in both PWS and sequential bilinguals. However, at present, there is no research on cerebral hemispheric processing for language in BWS. Differences in stuttering severity between languages in BWS might be due to a variance in language proficiency or age of language acquisition (Jankelowitz & Bortz, 1996; Schaefer & Robb, 2012), and these are similar factors thought to have an impact on hemispheric asymmetry among non-impaired bilinguals (Hull & Vaid, 2006, 2007). Therefore, it is reasonable to suggest that evaluation of cerebral hemispheric asymmetry in BWS will provide valuable information about the functional neural processes that influence bilingualism and stuttering.

2.7 Research Questions and Hypotheses

Based on findings of previous research on behavioural tests of hemispheric asymmetry with respect to either stuttering or bilingualism, the following hypotheses are proposed.

2.7.1 Comparison of MWS and MWNS

Comparisons of MWS and MWNS have been conducted in previous research investigating cerebral hemispheric processing in the disorder of stuttering. These earlier behavioural studies assessing hemispheric asymmetry in MWS (see Sections 2.4.3.1, 2.4.4.1, and 2.4.5.1) have indicated an asymmetry to the right hemisphere for language processing in MWS compared to MWNS.

Research Question: How do MWS compare to MWNS on functional cerebral hemispheric language processing?

Hypothesis 1

MWS have greater right-hemisphere dominance for functional cerebral hemispheric language processing over MWNS.

Hypothesis 1a: MWS will have significantly greater right-hemisphere dominance than MWNS on a dichotic listening paradigm.

Hypothesis 1b: MWS will have significantly greater right-hemisphere dominance than MWNS on a visual hemifield paradigm.

Hypothesis 1c: MWS will have significantly greater right-hemisphere dominance than MWNS on a dual-task paradigm.

2.7.2 Comparison of BWNS and MWNS

Comparisons of BWNS and MWNS have been conducted in previous research investigating cerebral hemispheric processing in the field of bilingualism. These earlier behavioural studies assessing hemispheric asymmetry in sequential BWNS (see Sections 2.4.3.2, 2.4.4.2, and 2.4.5.2) have indicated a greater asymmetry to the left hemisphere for language processing in BWNS compared to MWNS.

Research Question: How do BWNS compare to MWNS on functional cerebral hemispheric language processing?

Hypothesis 2

BWNS have greater left-hemisphere dominance for functional cerebral hemispheric language processing over MWNS.

Hypothesis 2a: BWNS will have significantly greater left-hemisphere dominance than MWNS on a dichotic listening paradigm.

Hypothesis 2b: BWNS will have significantly greater left-hemisphere dominance than MWNS on a visual hemifield paradigm.

Hypothesis 2c: BWNS will have significantly greater left-hemisphere dominance than MWNS on a dual-task paradigm.

2.7.3 Comparison of BWS and MWS

A comparison of BWS and MWS has not been conducted in previous research investigating cerebral hemispheric processing in the disorder of stuttering. Despite earlier behavioural studies assessing hemispheric asymmetry in MWS (see Sections 2.4.3.1, 2.4.4.1, and 2.4.5.1) or sequential BWNS (see Sections 2.4.3.2, 2.4.4.2, and 2.4.5.2), it is not known whether BWS and MWS have the same level of hemispheric asymmetry in language processing.

Research Question: How do BWS compare to MWS on functional cerebral hemispheric language processing?

Hypothesis 3

BWS have greater left-hemisphere dominance for functional cerebral hemispheric language processing over MWS.

Hypothesis 3a: BWS will have significantly greater left-hemisphere dominance than MWS on a dichotic listening paradigm.

Hypothesis 3b: BWS will have significantly greater left-hemisphere dominance than MWS on a visual hemifield paradigm.

Hypothesis 3c: BWS will have significantly greater left-hemisphere dominance than MWS on a dual-task paradigm.

2.7.4 Comparison of BWS and BWNS

A comparison of BWS and BWNS has not been conducted in previous research investigating cerebral hemispheric asymmetry in the disorder of stuttering. Despite earlier studies assessing hemispheric asymmetry in MWS (see Sections 2.4.3.1, 2.4.4.1, and 2.4.5.1) or sequential BWNS (see Sections 2.4.3.2, 2.4.4.2, and 2.4.5.2), it is not known how BWS and BWNS differ with respect to hemispheric asymmetry in language processing.

Research Question: How do BWS compare to BWNS on functional cerebral hemispheric language processing?

Hypothesis 4

BWS have greater right-hemisphere dominance for functional cerebral hemispheric language processing over BWNS.

Hypothesis 4a: BWS will have significantly greater right-hemisphere dominance than BWNS on a dichotic listening paradigm.

Hypothesis 4b: BWS will have significantly greater right-hemisphere dominance than BWNS on a visual hemifield paradigm.

Hypothesis 4c: BWS will have significantly greater right-hemisphere dominance than BWNS on a dual-task paradigm.

2.7.5 Rationale for Hypotheses 1 to 4

Findings for MWS on dichotic listening, visual hemifield and dual-task paradigms indicate atypical cerebral lateralisation (Foundas et al., 2004; Moore, 1976; Sussman, 1982). Bilateral hemispheric involvement has been found for speech and non-speech processing, as well as for motor control (Choo, Robb, Dalrymple-Alford, Huckabee, & O'Beirne, 2010; Fox et al., 2000). With respect to bilingualism, meta-analyses have found that sequential bilinguals display strong left hemisphere dominance in their first and second language (Hull & Vaid, 2006, 2007). Moreover, it has been suggested that sequential bilinguals demonstrate greater left hemisphere reliance for language compared to simultaneous bilinguals and monolinguals (Vaid, 1987). Therefore, both MWS and sequential bilinguals appear to show divergent patterns of language processing. The past finding of a spread of cerebral activation among PWS and a reliance of left hemisphere activation among sequential bilinguals presents an interesting paradox in regard to the BWS. Therefore, research examining BWS compared to MWS, as well as their non-stuttering controls, may provide new and important insight not only into the disorder of stuttering but also into the phenomenon of bilingualism. However, at present, there are no behavioural studies of hemispheric asymmetry that have investigated BWS.

2.7.6 Significance for Hypotheses 1 to 4

The aim of this research was to examine the relationship between stuttering and bilingualism to hemispheric asymmetry for the processing and production of language. As no previous studies have investigated BWS, evaluations of this particular population were required to gain further knowledge of the interaction of the two cerebral hemispheres during language processing and production. The examination of possible associations between stuttering and bilingualism may assist in determining the predictive value of these factors on language lateralisation. This could ultimately contribute to a better understanding of the disorder stuttering, as well as the nature of bilingualism.

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3. Methods

All procedures for this research study were reviewed and approved by the Human Ethics Committee of the University of Canterbury on 27 March 2013. The approval number is HEC 2013/13. Written consent was obtained from all participants, each of whom received a €5 voucher as compensation for participation.

3.1 Participants

Eighty right-handed adults were recruited in Germany to participate in this study.[1] The participants were 48 males and 32 females with a mean age of 38.9 years (range = 18-58 years). Participants were divided into four groups, consisting of 20 sequential BWS (12 males, 8 females) and 20 MWS (12 males, 8 females), as well as 40 controls including 20 sequential BWNS (12 males, 8 females) and 20 MWNS (12 males, 8 females). The four groups were controlled and matched for sex, age (+/- 5 years), and language. The participants' handedness was based on self-reports. The general characteristics of the four participant groups can be found in Appendix 7. The PWS participants were recruited by contacting the Deutscher Bundesverband für Logopädie e.V. (dbl; German Speech-Language Therapists' Association), Bundesvereinigung Stottern & Selbsthilfe e. V. (BVSS; National Association of Stutter Support Groups), individual stutter support groups, local SLPs, and placing advertisements (see Appendix 1) in Germany. In addition, the PWNS control groups (BWNS and MWNS) were recruited from the wider community. Prospective participants received an information sheet (see Appendix 2) with details of the study and were invited to discuss the project with the researcher. If they decided to join the study, they were required to complete a questionnaire concerning their languages spoken (see Appendix 3) and stuttering history (see Appendix 4) and to sign a consent form (see Appendix 5).

All participants were required to complete a language history questionnaire in order to obtain an estimation of their English language proficiency and assign them as either monolingual or bilingual. Self-rating scales have been found to be a reliable tool in research contexts to measure

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[1] Prior to data collection, statistical power was determined to decide on an appropriate sample size. In consultation with a statistician, it was calculated that a minimum sample size of 16 participants per group was required.

language proficiency in bilinguals (Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2012; Li, Sepanski, & Zhao, 2006; Lim, Rickard Liow, et al., 2008). The questionnaire used in the present study included an English proficiency self-rating scale ranging from 1 to 10 for listening, speaking, reading and writing. A brief written description of the level of English proficiency was given for each number. For example, the number one represented no English language skills at all, and the number 10 represented native-like English language skills. For the bilingual participants, German was spoken as L1 and English as L2. Participants were only considered to be bilingual if they rated themselves six or higher in all modalities. Moreover, participants were required to have had five or more years of formal study of the English language while using it on a regular basis. In order to be considered monolingual, participants needed a rating below three in all modalities. All people with a self-rating of four or five in any modality were excluded to keep the monolingual and bilingual groups strictly separated.

In order to be eligible for participation, each PWS was required to have: (a) developmental stuttering as diagnosed by a qualified SLP, and (b) no other communication disorder. The two PWS groups (BWS, MWS) were reasonably balanced with respect to stuttering severity and amount of previous treatment. All PWS, except for two MWS, were in treatment at the time of their study participation or had received speech therapy in the past. Prior to the assessment, all PWS were required to also complete a stuttering history questionnaire, which included a stuttering severity self-rating scale ranging from 1 to 9 (‘1’ indicates no stuttering and ‘9’ represents extremely severe stuttering). The self-rating scale has been found to be a reliable clinical tool in research contexts to measure stuttering severity (Karimi, Jones, O'Brian, & Onslow, 2014; O'Brian, Packman, & Onslow, 2004). The stutter severity for the PWS groups ranged from 2 to 9 as estimated on the stuttering severity self-rating scale. The self-rating for each participant was in general agreement with the researcher’s impression of their stuttering severity, as well as with the estimation of eight SLPs rating their patients (20% of whole sample of PWS). The researcher and SLP estimations of stuttering severity were also based on the stuttering severity self-rating scale.

Participants were excluded from the study if they reported having a significant medical (neurological, psychological) condition, or presented with a diagnosed hearing impairment, or acquired neurogenic stuttering. Research participants were fully entitled to terminate their involvement in the study at any time.

3.2 Research Design

All participants were seen individually in a quiet area with minimal distraction either at a clinic, speech-language pathology private practice or their home, depending on the participant's preference and availability of office space. The researcher, who is a qualified SLP and a proficient German-English bilingual, administered the tests. The assessment took approximately 1.5 hours for the monolingual participants and 2 hours for the bilingual participants. All tests were administered within one session, and the participants were able to request breaks at any time between tests during the assessment. Three behavioural tests of hemispheric asymmetry were administered to all participants: a dichotic listening paradigm, a visual hemifield paradigm, and a dual-task paradigm. All participants completed the tests in the following order: (1) dichotic listening paradigm, (2) visual hemifield paradigm (German), and (3) dual-task paradigm (German). In addition, bilingual participants also completed the (4) visual hemifield paradigm (English) and (5) dual-task paradigm (English) subsequent to the first three tests. However, the data collected for the English versions were not analysed or included as part of the current study.

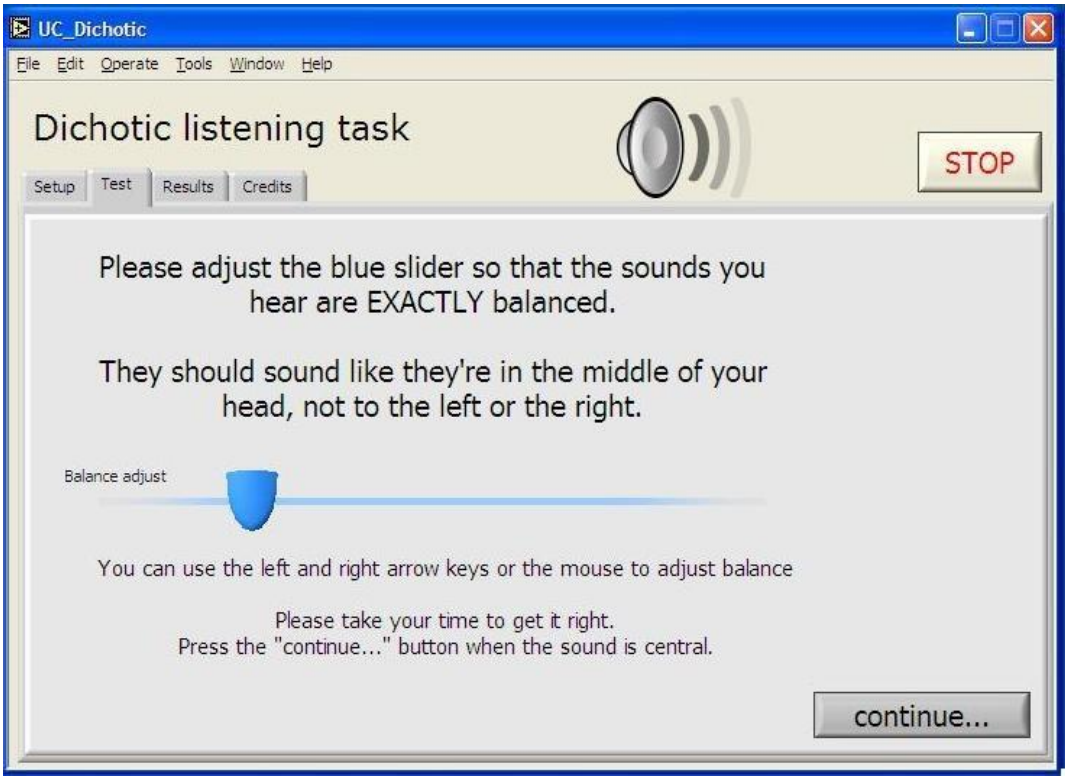
3.2.1 Dichotic Listening Paradigm

An undirected dichotic listening task was used to assess hemispheric involvement for language processing. The dichotic listening paradigm used in this study was slightly modified from a study by Robb et al. (Robb et al., 2013) (see also Lynn, 2010), who investigated dichotic listening among AWS. The dichotic listening paradigm consisted of six CV syllables as stimuli. These syllables included /ba/, /da/, /ga/, /pa/, /ta/ and /ka/, resulting in three voiced (/ba/, /da/, /ga/) and three unvoiced (/pa/, /ta/, /ka/) syllables. A recording of the CV tokens was made using an adult male native speaker of New Zealand English. The dichotic listening test was administered and digitally controlled on an Acer netbook, and the dichotic stimuli delivered via headphones (Sennheiser, HD 280 professional). A specially designed software programme was used to present the CV syllables, to analyse the responses, and to display the results. Test instructions were given verbally prior to the start of the assessment when participants were seated in a relaxed position in front of the computer. The test instructions were given in German as follows (English translation):

"You are going to complete an auditory task. I will go through the instructions at the beginning of the task and you will also have the instructions displayed on the screen in front of you. The task should take about 30 minutes."

In preparation for the undirected task, participants were required to first complete a perceptual calibration listening task (see Figure 4). This task was designed to establish the interaural intensity balance for each participant to account for any audiometric perceptual asymmetries of the individuals hearing, which would influence the results when changing the IID. Participants were fitted with headphones while facing the computer. Each CV was presented simultaneously via the headphones and was repeated continuously at two-second intervals. During this iterative process, participants were required to move a linear slide bar to a location where the CV was heard equally in both ears. This procedure was completed for all of the six CV syllables. The median score of the slider position was used as the interaural intensity balance for this particular participant. The instructions for the perceptual calibration task were given in German as follows (English translation):

"You are going to hear some speech sounds in the form of syllables. You are required to listen to the repeating sounds and adjust the blue slider so that the sounds you hear are exactly balanced, meaning that the sounds appear to be coming from both ears equally. They should sound like they're in the middle of your head, not to the left or the right. You can use the left and right arrow keys or the mouse to adjust balance. The slider may not necessarily be in the centre for each sound. Press the 'continue' button when the sound is central. There are six different speech sounds in total. This task will take approximately 5 minutes. Once this task is complete, I will give you the instructions for the actual test."



Please adjust the blue slider so that the sounds you hear are EXACTLY balanced.

They should sound like they're in the middle of your head, not to the left or the right.

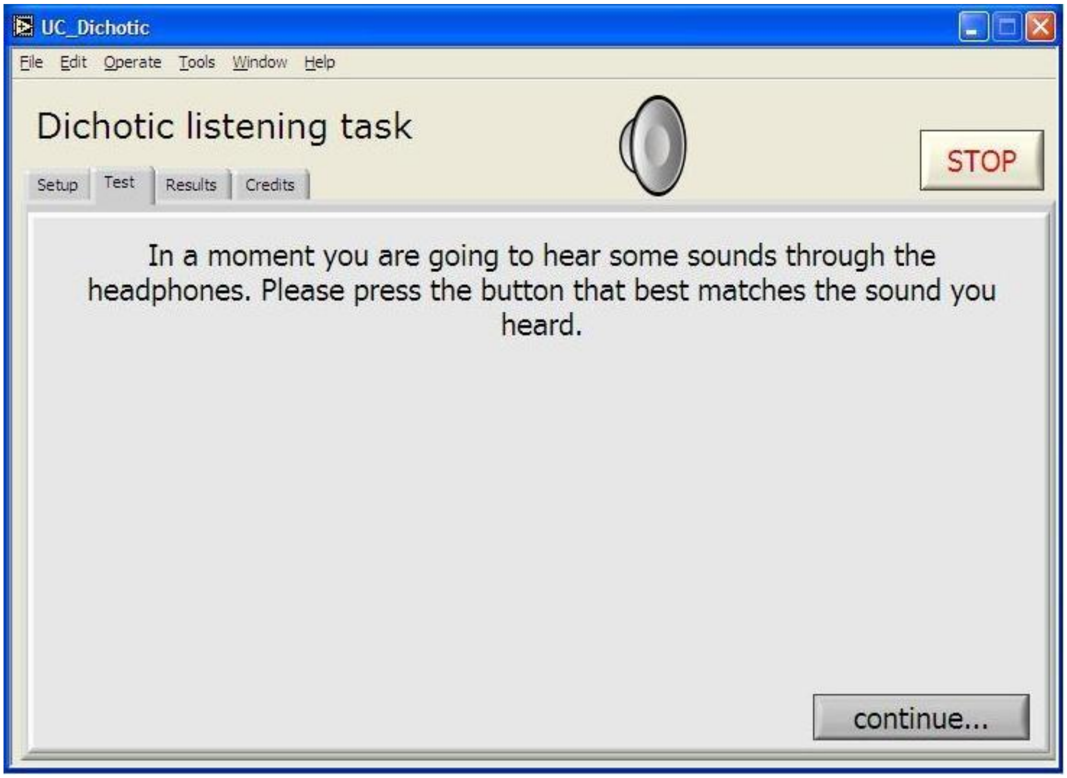
You can use the left and right arrow keys or the mouse to adjust balance

Please take your time to get it right.
Press the "continue..." button when the sound is central.

Figure 4. Screenshot of the perceptual calibration listening task for the dichotic listening paradigm.

Once the interaural intensity balance was obtained, participants commenced with the undirected dichotic listening task (see Figures 5 and 6). In total, 12 CV stimulus pairs were created, pairing six combinations of the three unvoiced CVs and six combinations of the three voiced CVs. The level of each syllable was adjusted to ensure presentation at 70 dB during the testing. Each of the 12 CV pairs was presented at 15 different IIDs, resulting in 180 intensity-stimulus pairs, where the IID was randomly varied for the left and right ear. A range of -21 dB to 21 dB was used to vary the IID, with -3 dB to -21 dB indicating greater intensity in the left ear, 0 dB being equal intensity levels in the left and right ear, and 3 dB to 21 dB indicating greater intensity in the right ear. The presentation order was pseudo-randomised. Following past research, a specially designed software programme controlled the pseudo-randomization for the IID task by using four rules to avoid learning and order effects (Hugdahl et al., 2008). The following restrictions within and between blocks were applied: a) not more than two consecutive trials with the same intensity difference condition, (b) not more than three consecutive trials with the same direction of intensity advantage, (c) no presentations of the same syllable to the same ear in consecutive trials and, (d) no repetition of a syllable pair in two consecutive trials. Test instructions were given both verbally and orthographically. Each stimulus was presented via headphones and also displayed on the computer screen. The response was collected by a mouse click, matching the verbal stimuli with the corresponding orthographic display on the screen. The stimuli pairs were presented in blocks of 45 presentations, followed by a short break. The verbal instructions for the undirected dichotic listening task were given in German as follows (English translation):

"You are going to hear two different speech sounds through the headphones. The sounds are played into both ears at the same time, one to the left ear and one to the right ear. You are then required to select the button from the screen that best matches the sound you heard most clearly. There will be breaks in this test, where you can select to have a break or to continue the test. You might find it easier to listen to each sound presentation while closing your eyes. The instructions for this test are also displayed on the screen. Once you have read these, press 'continue' and the first presentation will start immediately. The test will take approximately 25 minutes."



In a moment you are going to hear some sounds through the headphones. Please press the button that best matches the sound you heard.

Figure 5. Screenshot of the undirected dichotic listening task instructions.

Please select the sound you hear...

Figure 6. Screenshot of an example for one of the speech sound combinations in the dichotic listening paradigm.

3.2.2 Visual Hemifield Paradigm

A bilateral visual hemifield picture-naming task was used to assess hemispheric involvement for language processing. There are a number of requirements that have been determined for the development of a good visual hemifield paradigm to assess language dominance (Bourne, 2006; Hunter & Brysbaert, 2008). Based on those methodological considerations, Hunter and Brysbaert (2008) designed two visual hemifield experiments, which were confirmed in a subsequent fMRI based validation study to reliably predict cerebral dominance for language. The visual hemifield paradigm, developed by Hunter and Brysbaert, was replicated and slightly modified in the present study. It consisted of five pictures as stimuli, which all represent high frequency monosyllabic words. The pictures included a boat, tree, book, lamp and house, and they are illustrated in Figure 7. Each picture was displayed and named 16 times within the LVF and 16 times within the RVF, which resulted in 160 pictures to be named in total. Bilingual participants performed each task in German and English with equivalent stimuli, whereas monolingual participants performed the task only in German. The visual hemifield test was administered and digitally controlled on an Apple MacBook Pro notebook. A specially designed software programme was used to present the visual stimuli, to analyse the responses, and to display the results. The order of the presentation of the stimuli was pseudo-randomized with this software.

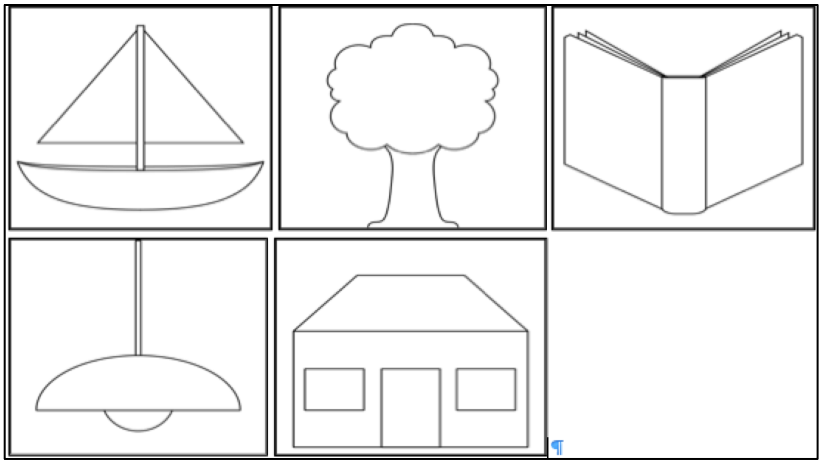


Figure 7. Screenshot of the five picture stimuli (boat, tree, book, lamp, house) used for the visual hemifield paradigm.

Participants viewed a monitor at a distance of about 60 cm and initiated the onset of the task by pressing the spacebar on the keyboard. At the beginning of each trial, they were asked to fixate on a cross for 1000 ms in the centre of the screen (fixation-space). The fixation cross is illustrated in Figure 8. Five symmetrical line drawings (house, tree, boat, lamp, and book) were presented repeatedly in a randomized order and stayed on the screen for 100 ms each. The present study was originally designed to present the visual stimuli for a duration of 200 ms. However, a decision was made to reduce stimuli exposure to 100 ms based on pilot research, which found the task to be too easy for the participants (e.g., an absence of errors). As per Hunter and Brysbaert (2008), the pictures were presented at a visual angel of approximately 2º from fixation with the outer edge at approximately 11º. The presentation occurred in a bilateral fashion, which means that one picture was presented in the LVF, while another was simultaneously presented in the RVF. Bilateral presentation was controlled in such a way that no matching pictures were displayed at the same time. The picture to be named was indicated by an arrow that was flashed in the fixation space simultaneously with the bilaterally presented pictures (see Figure 8). This ensured midline fixation throughout the assessment, since the arrow gave the cue to which side to attend to in order to give a correct response. Participants were then required to select as quickly as possible the word that corresponded with the picture (see Figure 8). The five words were always arranged in a circle with the computer mouse in the centre. In case participants were not sure which picture they had seen, they were asked to guess when selecting the corresponding word. There were no breaks in this test, but participants were able to decide for themselves when they were ready to continue to the next pictures by pressing ‘ok’. Once they had pressed ‘ok’, the next pictures followed immediately. Responses were collected by means of a mouse click, where the onset of the click was registered as reaction time for a specific stimulus. The five pictures were shown to the participants beforehand to ensure familiarisation with the stimuli. Test instructions were given verbally prior to the start of the assessment when participants were seated in a relaxed position in front of the computer. The test instructions were given in German as follows (English translation):

“You are going to see two different pictures. The pictures are briefly flashed into both eyes at the same time, one to the left of the screen and one to the right of the screen. At the beginning of each trial, please stare at the fixation point in the form of a cross in the centre of the screen. An arrow will be flashed in the fixation space simultaneously with the presented pictures, indicating the picture to be named. You are then required to select as quickly as possible the word, out of five, that corresponds with the picture. The words are always arranged in a circle with the mouse in the centre. If you are not sure which picture it was, please take a guess when selecting the corresponding word. There will be no breaks in this test, but you can decide for yourself when you would like to continue to the next pictures by pressing ‘ok’. Once you have pressed ‘ok’, the next pictures will follow immediately. In total, five different pictures and their corresponding words are used, including a house, a tree, a boat, a lamp and a book. It is important that you respond as accurately and quickly as possible. You are able to initiate the onset of the test by pressing the spacebar. The test will take approximately 15 minutes.”

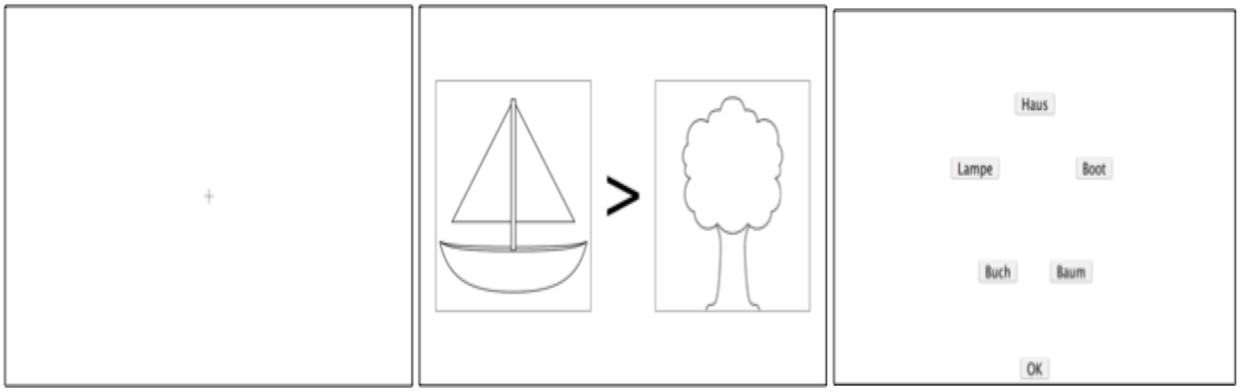


Figure 8. Screenshot of fixation cross, stimuli presentation, and response collection for the visual hemifield paradigm.

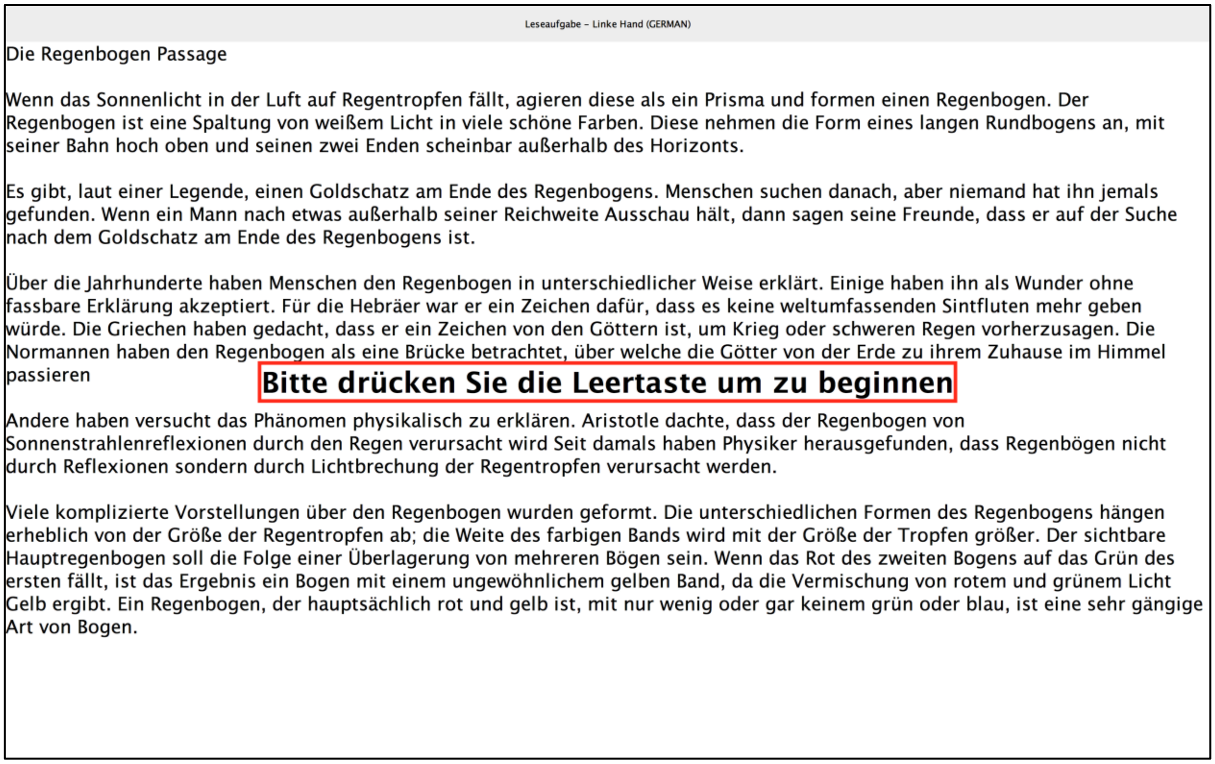
3.2.3 Dual-Task Paradigm

Two linguistic tasks were used concurrently with finger-tapping to assess hemispheric involvement for language production. Similar materials and procedure have been used previously in investigations assessing dual-task performance (Badzakova-Trajkov et al., 2008; Furtado & Webster, 1991; Green, 1986; Hall & Lambert, 1988; Soares, 1984). The dual-task tests were administered and digitally controlled on an Apple MacBook Pro notebook. Finger-tapping was measured by the MacBook Pro trackpad and controlled by a 60s interval timer activated by the first finger tap on each trial. During the testing, participants were required to sit with both of their hands placed on top of a table, and to keep the forearm of the tapping hand in contact with the tabletop in order to prevent whole arm movements. The heel of the hand and all fingers except the index finger were rested on the top surface of the notebook. All participants were instructed to (1) not look at their hand while tapping, (2) keep their hand steady while tapping, (3) move only the index finger of the tapping hand, and (4) always tap as fast as possible, while performing all language tasks at a normal speaking rate. The researcher provided a demonstration of the desired finger-tapping procedure to each participant prior to data collection. Also, participants were frequently re-reminded between the tasks to tap as fast as possible on all trials. A single-task, consisting of rapid left finger-tapping and rapid right finger-tapping alone, was used to establish a baseline. Two verbal dual-tasks were employed, including concurrent finger-tapping while (a) reading 'The Rainbow Passage' (see Appendix 6) aloud and (b) reciting automatisms (i.e., counting). A screenshot of the dual-task paradigm is provided in Figure 9.

Each task was performed for 60s and consisted of two trials. The tapping hand was alternated after each trial, which resulted in one trial for each hand. The tapping hand was altered after each trial in order to avoid fatigue of the hands. Bilingual participants performed each task in German and English with equivalent stimuli, whereas monolingual participants performed the task only in German. Test instructions were given verbally prior to the start of the assessment when participants were seated in a relaxed position in front of the computer. Instructions were also displayed in the top centre of the screen, indicating which task was required to be performed. The participants were able to initiate the onset of each task by pressing the spacebar, with the first tap on the trackpad activating the 60 s interval timer on each trial. The test instructions were given in German as follows (English translation):

"You are going to perform two verbal tasks in combination with finger-tapping. This test consists of several different parts. First, you are required to perform left finger-tapping and right finger-tapping alone. You will then complete two different verbal tasks, reading aloud and counting, that involve concurrent finger-tapping. Last, you are again required to perform left finger-tapping and right finger-tapping alone. Each task will be performed for 60 seconds and consists of two trials, one for the left hand and one for the right hand. The tapping hand is alternated after each trial, and you are able to take short breaks in-between if needed. You are required to sit with both hands placed on top of the table, and to keep the forearm of the tapping hand in contact with the tabletop in order to prevent whole arm movements. Please do not look at your hand while tapping, and make sure to keep your hand steady while moving only the index finger. It is important that you always tap as fast as possible, but to perform all language tasks at a normal rate. For the reading task, you are required to read the passage presented out loud and as accurately as possible. Please read the passage with purpose, as I will ask you questions after you have finished reading. For the counting task, you are required to count starting from number 1 until 60 seconds have elapsed. The instructions for this test are also displayed in the top centre of the screen, indicating which task is required to be performed. You are able to initiate the onset of each task by pressing the spacebar, and the first tap on the trackpad will activate the 60 seconds interval timer on each trial. The test will take approximately 10 minutes."

The single-task performance was recorded in order to establish a tapping baseline for the left and right hand. The Rainbow Passage (Fairbanks, 1960) was used to the reading aloud dual-task. The passage was displayed on the computer screen for 60 s. Participants were required to read the passage presented to them aloud and as accurately as possible. Moreover, participants were instructed to read the passage with purpose, as they were asked to give a brief summary afterwards to ensure comprehension of the text. For the reciting automatisms dual-task, participants were required to count starting from number 1 until 60 s had elapsed.



Die Regenbogen Passage

Wenn das Sonnenlicht in der Luft auf Regentropfen fällt, agieren diese als ein Prisma und formen einen Regenbogen. Der Regenbogen ist eine Spaltung von weißem Licht in viele schöne Farben. Diese nehmen die Form eines langen Rundbogens an, mit seiner Bahn hoch oben und seinen zwei Enden scheinbar außerhalb des Horizonts.

Es gibt, laut einer Legende, einen Goldschatz am Ende des Regenbogens. Menschen suchen danach, aber niemand hat ihn jemals gefunden. Wenn ein Mann nach etwas außerhalb seiner Reichweite Ausschau hält, dann sagen seine Freunde, dass er auf der Suche nach dem Goldschatz am Ende des Regenbogens ist.

Über die Jahrhunderte haben Menschen den Regenbogen in unterschiedlicher Weise erklärt. Einige haben ihn als Wunder ohne fassbare Erklärung akzeptiert. Für die Hebräer war er ein Zeichen dafür, dass es keine weltumfassenden Sintfluten mehr geben würde. Die Griechen haben gedacht, dass er ein Zeichen von den Göttern ist, um Krieg oder schweren Regen vorherzusagen. Die Normannen haben den Regenbogen als eine Brücke betrachtet, über welche die Götter von der Erde zu ihrem Zuhause im Himmel passieren

Bitte drücken Sie die Leertaste um zu beginnen

Andere haben versucht das Phänomen physikalisch zu erklären. Aristotle dachte, dass der Regenbogen von Sonnenstrahlenreflexionen durch den Regen verursacht wird Seit damals haben Physiker herausgefunden, dass Regenbögen nicht durch Reflexionen sondern durch Lichtbrechung der Regentropfen verursacht werden.

Viele komplizierte Vorstellungen über den Regenbogen wurden geformt. Die unterschiedlichen Formen des Regenbogens hängen erheblich von der Größe der Regentropfen ab; die Weite des farbigen Bands wird mit der Größe der Tropfen größer. Der sichtbare Hauptregenbogen soll die Folge einer Überlagerung von mehreren Bögen sein. Wenn das Rot des zweiten Bogens auf das Grün des ersten fällt, ist das Ergebnis ein Bogen mit einem ungewöhnlichem gelben Band, da die Vermischung von rotem und grünem Licht Gelb ergibt. Ein Regenbogen, der hauptsächlich rot und gelb ist, mit nur wenig oder gar keinem grün oder blau, ist eine sehr gängige Art von Bogen.

Figure 9. Screenshot of the reading task for the dual-task paradigm.

3.3 Data Analysis

Statistical analyses were undertaken using IBM SPSS Statistics 21. A lack of homogeneity in group variance and non-normally distributed data were found across each of the participant groups. Accordingly, a decision was made to use non-parametric statistics for all analyses. The Mann-Whitney U Test, the Wilcoxon Signed Rank Test, the Hodges-Lehman Estimator, and the Spearman’s Correlation were used. The data analysis was solely focused on the results obtained for the German language, since only two participant groups (BWS, BWNS) were proficient speakers of English but all four participant groups (BWS, MWS, BWNS, MWNS) were native speakers of German.

3.3.1 Dichotic Listening Paradigm

A laterality index (LI) was calculated showing the percentage difference between the correct left and right ear identifications, using the formula [(RE-LE)/(RE+LE)] x 100, where RE and LE stand for the number of responses reporting the right or left ear speech stimuli, respectively. The LI ranged from -100% to +100%, with negative values indicating a LEA and positive values indicating a REA. This analysis shows the change in the degree of REA between two intensity levels, where there is a reduction in the magnitude of REA as the stimulus intensity level is increased for the left ear. In the same respect, there is an increase in the magnitude of the REA when the right ear stimulus is more intense. The magnitude of these differences was compared, using the correct report of responses for the right ear and the correct report of responses for the left ear. Cross-over levels ranging from -1 dB to -21 dB indicated greater intensity of the left ear, 0 dB being equal intensity levels in the left and right ear, and 1 dB to 21 dB indicated greater intensity in the right ear. Two scores were obtained, including (1) the equal binaural intensity of 0 dB (L=R), and (2) the IID, indicating the cross-over point from a REA to a LEA. Group means and medians were obtained for each group.

For all statistical comparisons, Mann-Whitney U Tests were run to determine if there were differences in the L=R and IID conditions between the four participant groups. An exact sampling distribution for U was used, with an alpha level of .05 (2-sided). The Hodges–Lehmann estimator, with a 95% lower and upper confidence interval (CI), was used to measure the effect size of the median differences between the groups.

3.3.2 Visual Hemifield Paradigm

To analyse the data set, all naming errors were eliminated from the data and mean reaction times were calculated for the LVF and RVF. Subsequently, the total number of errors were calculated for the LVF and RVF. For both reaction time and errors, a LI was derived through the following formula:

LI for reaction time (RT) = RT for the LVF (RT_LVF) – RT for the RVF (RT_RVF)

LI for errors (E) = Errors for the LVF (E_LVF) – Errors for the RVF (E_RVF)

This information was used to determine the visual hemifield (VHF) advantage of each participant for reaction times and errors. Negative LI values represented a LVF advantage and positive values represented a RVF advantage. Prior to statistical analysis, a data normalisation procedure was completed. The data were normalised (1) due to non-normal distribution of data and (2) in order to rescale the data for group comparisons, whereby the mean reaction time for the LVF and RVF was calculated (the same was done with errors using the same formula):

$$\frac{LVF + RVF}{2}$$

The normalised differences (ND) for reaction time and errors were derived from:

$$\frac{LVF - RVF}{mean\ reaction\ time}$$

$$\frac{LVF - RVF}{mean\ errors}$$

Reaction time left/right and errors left/right were also considered independently. In total, eight scores were obtained in the visual hemifield paradigm: 1) VHF advantage for reaction time, (2) ND for reaction time, (3) LVF reaction time, (4) RVF reaction time, (5) VHF advantage for errors, (6) ND for errors, (7) LVF errors, and (8) RVF errors. Group means and medians were obtained for each group.

For all statistical comparisons, Mann-Whitney U Tests were run to determine if there were differences in reaction time and error rate conditions between the four participant groups. An exact sampling distribution for U was used, with an alpha level of .05 (2-sided). The Hodges–

Lehmann estimator, with a 95% lower and upper CI, was used to measure the effect size of the median differences between the groups.

3.3.3 Dual-Task Paradigm

The percentage change in finger-tapping for each hand during each concurrent task was computed. Each participant's finger-tapping rate for the left and right hand was measured relative to the single-task control finger-tapping conditions (baseline). The following formula was used:

$$\text{Percent change score (per hand)} = \frac{No.\ taps\ single{-}task\ - No.\ taps\ dual{-}task}{No.\ taps\ single{-}task}$$

The same formula to calculate the percentage change in finger-tapping has been used previously (Simon & Sussman, 1987; Soares, 1984). This calculation is performed because participants generally tap faster with their preferred hand. As a result, participants tap at different rates and raw tapping scores are unequal for the two hands. A positive value indicated a decrement or disruption in tapping rate (i.e., concurrent tapping rate is slower than baseline tapping rate), whereas a negative value indicated an increment in tapping rate (i.e., concurrent tapping rate is faster than baseline tapping rate). Reading rate or reading accuracy was not recorded. The following four scores were obtained: (1) percent change score during reading and tapping with the left hand (PCS-RL), (2) percent change score during reading and tapping with the right hand (PCS-RR), (3) percent change score during counting and tapping with the left hand (PCS-CL), and (4) percent change score during counting and tapping with the right hand (PCS-CR). Group means and medians were obtained for each group.

For all group comparisons, Mann-Whitney U Tests were run to determine if there were differences in the reading and counting conditions between the four participant groups. An exact sampling distribution for U was used, with an alpha level of .05 (2-sided). For all task comparisons, Wilcoxon Signed Rank Tests were run to determine if there were differences within and between reading and counting conditions depending on the tapping hand for the four participant groups. Asymptotic significances were used, with an alpha level of .05 (2-sided). The

Hodges–Lehmann estimator, with a 95% lower and upper CI, was used to measure the effect size of the median differences between the groups and tasks.

4. Results

4.1 Dichotic Listening Paradigm

The individual participant scores for the (1) L=R and (2) IID conditions can be found in Appendix 8. The group results for each of the four participant groups are listed in Table 1 and displayed in Figures 10 and 11 as box and whisker plots.

BWS versus MWS

No significant differences were found between groups for the L=R (p = .211) and IID (p = .165) conditions.

BWS versus BWNS

No significant differences were found between groups for the L=R (p = .301) and IID (p = .925) conditions.

MWS versus MWNS

No significant differences were found between groups for the L=R (p = .495) and IID (p = .820) conditions.

BWNS versus MWNS

No significant differences were found differences between groups for the L=R (p = .640) and IID (p = .301) conditions.

Table 1. *Dichotic Listening Results for all Participant Groups.*

	BWS		**BWNS**		**MWS**		**MWNS**	
	L=R (%)	**IID (dB)**	**L=R (%)**	**IID (dB)**	**L=R (%)**	**IID (dB)**	**L=R (%)**	**IID (dB)**
Mean	22	-76	16	6	12	19	20	42
SD	27	263	28	54	20	31	34	105
Median	25	13	8	8	8	18	20	11
Range	-25 – 75	-1100 – 170	-25 – 91	-99 – 140	-16 – 58	-42 – 71	-33 – 91	-56 – 390

Note. ***L=R:*** Equal Binaural Intensity, IID = 0 dB (%); ***IID:*** Interaural Intensity Difference; ‘cross-over point’ (dB)

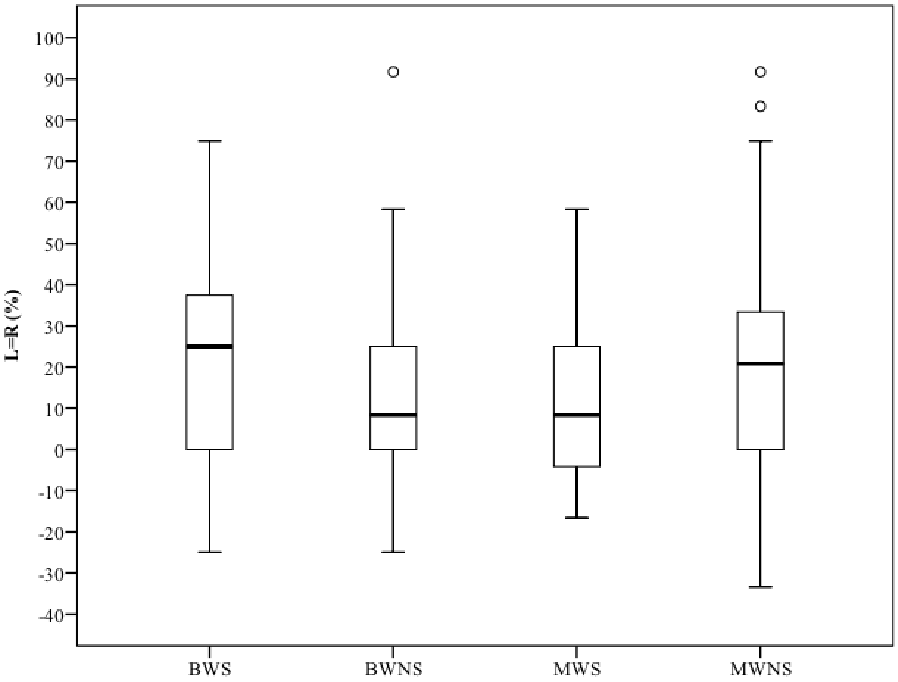


Figure 10. Median score, interquartiles, and range for the L=R condition. Note: ° = outliers.

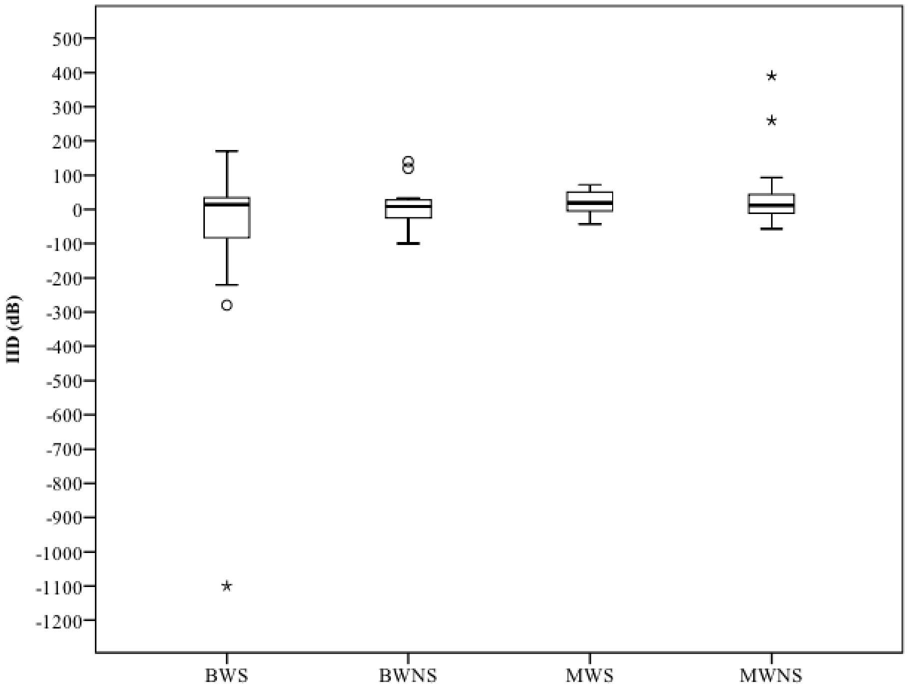


Figure 11. Median score, interquartiles, and range for the IID condition. Note: ° = outliers; * = extreme outliers.

4.2 Visual Hemifield Paradigm

The individual participant scores for the (1) VHF advantage for reaction time, (2) ND for reaction time, (3) LVF reaction time, (4) RVF reaction time, (5) VHF advantage for errors, (6) ND for errors, (7) LVF errors, and (8) RVF errors conditions can be found in Appendix 9. The group results for each of the four participant groups are listed in Tables 2 to 5 and displayed in Figures 12 to 19 as box and whisker plots.[2] The effect size is reported for all significant findings using the Hodges-Lehmann estimator.

BWS vs. MWS

The LVF reaction time was lower in BWS (*Mdn* = 1756 ms) than in MWS (*Mdn* = 1989 ms), p = .003, with a Hodges-Lehman median difference of -288 ms (95% CI = -534 ms to -108 ms). The same was found for the RVF reaction time, which was lower in BWS (*Mdn* = 1834 ms) than in MWS (*Mdn* = 2074 ms), p = .006, with a Hodges-Lehman median difference of -304 ms (95% CI = -618 ms to -84 ms). No significant differences were found between groups for the VHF advantage (p = .396) and ND (p = .270) reaction time conditions.

The LVF errors were lower in BWS (*Mdn* = 2 errors) than in MWS (*Mdn* = 10 errors), p = .023, with a Hodges-Lehman median difference of -7 errors (95% CI = -13 errors to -1 error). The same was found for the RVF errors, which were lower in BWS (*Mdn* = 3 errors) than in MWS (*Mdn* = 8 errors), p = .001, with a Hodges-Lehman median difference of -6 errors (95% CI = -13 errors to -2 errors). No significant differences were found between groups for the VHF advantage (p = .134) and ND (p = .108) error conditions.

BWS vs. BWNS

No significant differences were found between groups for the LVF (p = .166), RVF (p = .184), VHF advantage (p = .588), and ND (p = .708) reaction time conditions, or LVF (p = .968), RVF (p = .841), VHF advantage (p = .341), and ND (p = .547) error conditions.

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[2] Complete data for the Visual Hemifield Paradigm were obtained from 79 participants, and incomplete data from participant 12 of the BWS group. The data from this participant were not included in the statistical analysis of the reaction time conditions since the participant failed to provide any correct answers for the visual stimuli presented to the RVF.

MWS vs. MWNS

No significant differences were found between groups for the LVF (p = .056), RVF (p = .063), VHF advantage (p = .779), and ND (p = .968) reaction time conditions. In contrast, the number of RVF errors was higher in MWS (*Mdn* = 8 errors) than in MWNS (*Mdn* = 3 errors), p = .009, with a Hodges-Lehman median difference of 5 errors (95% CI = 1 error to 12 errors). No significant differences were found between groups for the LVF (p = .060), VHF advantage (p = .142), and ND (p = .718) error conditions.

BWNS vs. MWNS

The LVF reaction time was lower in BWNS (*Mdn* = 1568 ms) than in MWNS (*Mdn* = 1756 ms), p = .009, with a Hodges-Lehman median difference of -216 ms (95% CI = -381 ms to -53 ms). The same was found for the RVF reaction time, which was lower in BWNS (*Mdn* = 1642 ms) than in MWNS (*Mdn* = 1833 ms), p = .024, with a Hodges-Lehman median difference of -206 ms (95% CI = -393 ms to -34 ms). No significant differences were found between groups for the VHF advantage (p = .678) and ND (p = .602) reaction time conditions. No significant differences were found between groups for the LVF (p = .565), RVF (p = .398), VHF advantage (p = .698.), and ND (p = .369) reaction time conditions.

Table 2. *Visual Hemifield Results for the BWS Group.*

BWS	**Reaction Time**				**Errors**			
	LVF (ms)	**RVF (ms)**	**VHFA (ms)**	**ND (%)**	**LVF**	**RVF**	**VHFA**	**ND (%)**
Mean	1733	1849	-115	-6	4	7	-3	12
SD	263	332	138	6	5	17	18	116
Median	1756	1834	-90	-6	2	3	0	20
Range	1263 – 2422	1344 – 2880	-458 – 51	-18 – 2	0 – 22	0 – 80	-78 – 13	-190 – 200

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

Table 3. *Visual Hemifield Results for the BWNS Group.*

BWNS	**Reaction Time**				**Errors**			
	LVF (ms)	**RVF (ms)**	**VHFA (ms)**	**ND (%)**	**LVF**	**RVF**	**VHFA**	**ND (%)**
Mean	1654	1713	-59	-4	3	4	0	-7
SD	324	252	191	10	4	5	3	116
Median	1568	1642	-78	-5	2	3	-1	-12
Range	1261 – 2634	1348 – 2180	473 – 466	-24 – 19	0 – 18	0 – 21	-8 – 5	-200 – 200

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

Table 4. *Visual Hemifield Results for the MWS Group.*

MWS	**Reaction Time**				**Errors**			
	LVF (ms)	**RVF (ms)**	**VHFA (ms)**	**ND (%)**	**LVF**	**RVF**	**VHFA**	**ND (%)**
Mean	2160	2247	-87	-3	13	15	-2	-38
SD	561	572	146	6	12	13	6	74
Median	1989	2074	-45	-1	10	8	-2	-30
Range	1561 – 3584	1490 – 3644	-400 – 71	-17 – 4	0 – 52	2 – 44	-15 – 9	-200 – 72

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

Table 5. *Visual Hemifield Results for the MWNS Group.*

MWNS	**Reaction Time**				**Errors**			
	LVF (ms)	**RVF (ms)**	**VHFA (ms)**	**ND (%)**	**LVF**	**RVF**	**VHFA**	**ND (%)**
Mean	1863	1937	-74	-3	6	6	0	-44
SD	302	326	139	6	7	5	4	101
Median	1756	1833	-45	-2	3	3	-1	-53
Range	1461 – 2750	1404 – 2677	-402 – 90	-18 – 4	0 – 28	1 – 19	-9 – 10	-200 – 125

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

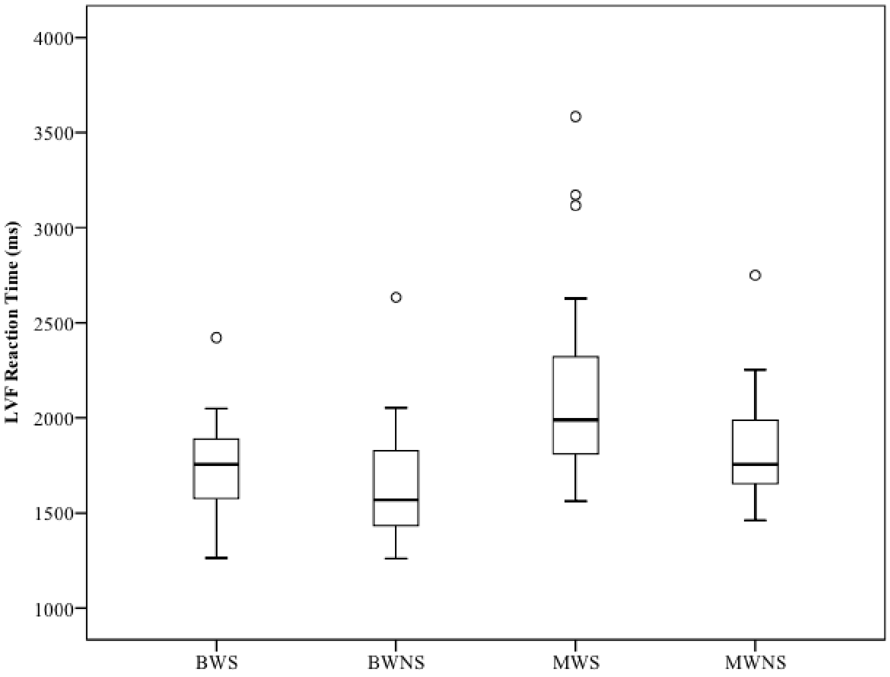

Figure 12. Median score, interquartiles, and range for the LVF reaction time condition. Note: ° = outliers.

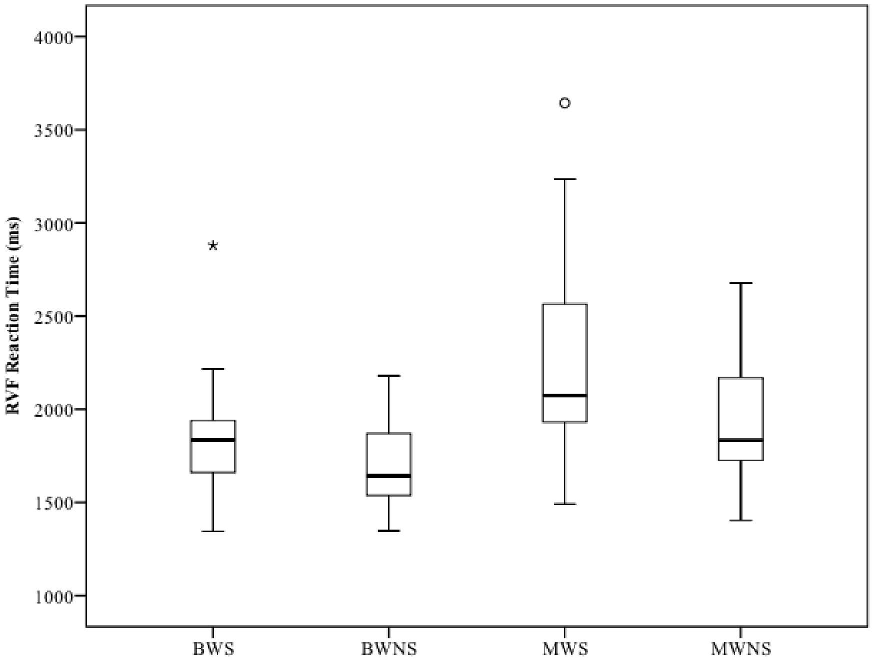

Figure 13. Median score, interquartiles, and range for the RVF reaction time condition. Note: ° = outliers; * = extreme outliers.

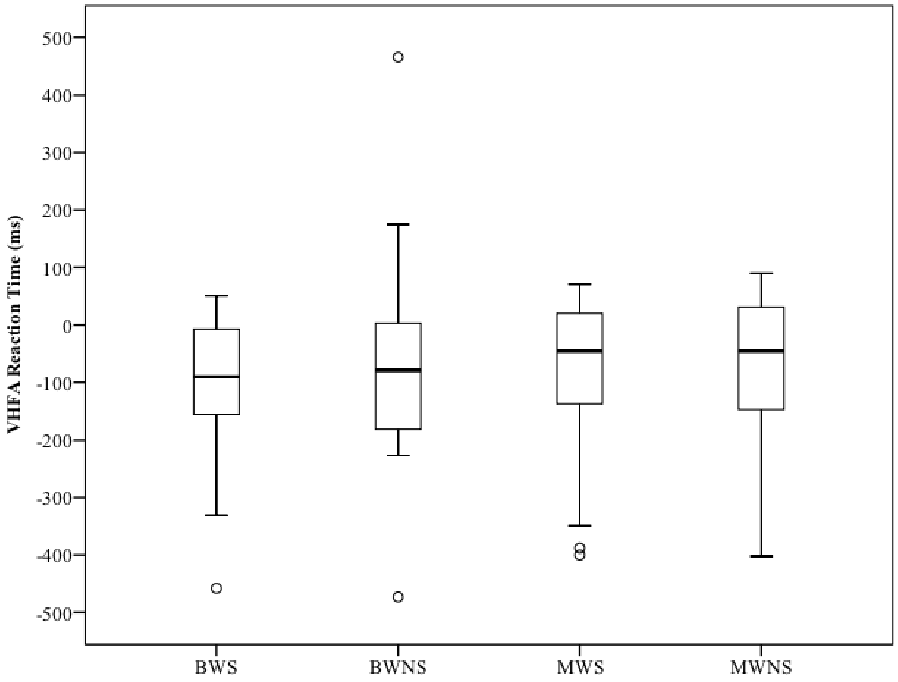

Figure 14. Median score, interquartiles, and range for the VHFA reaction time condition. Formula: $LI_{(VHF)}$ = (RT_LVF) – (RT_RVF). Negative values = LVF advantage; Positive values = RVF advantage. Note: ° = outliers.

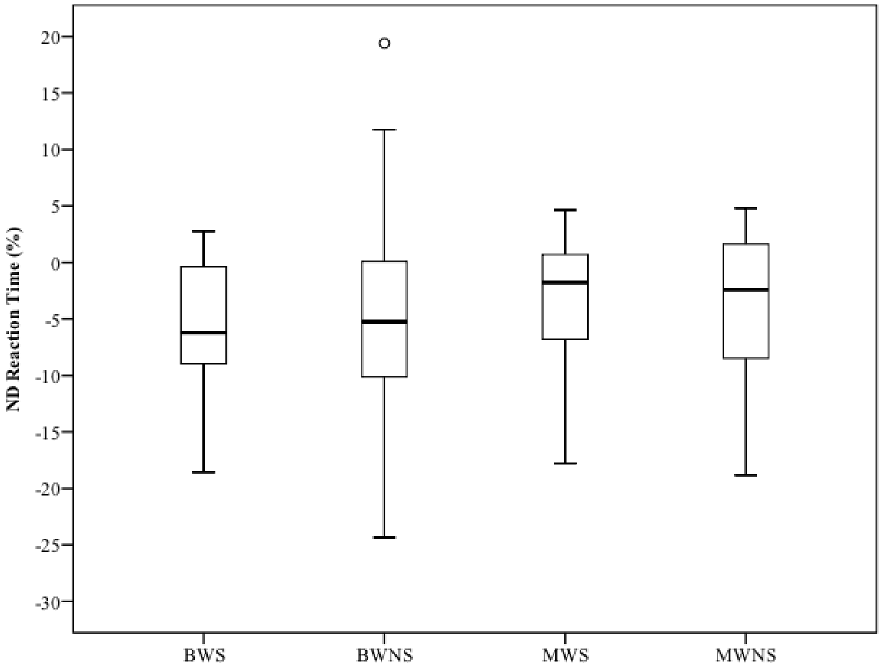

Figure 15. Median score, interquartiles, and range for the ND reaction time condition. Note: ° = outliers.

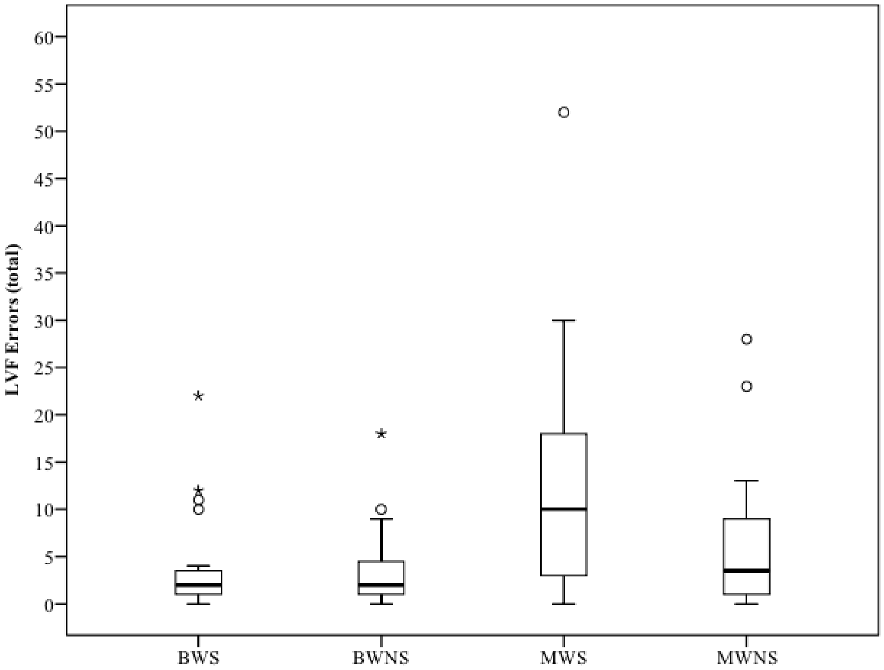

Figure 16. Median score, interquartiles, and range for the LVF error condition. Note: ° = outliers; * = extreme outliers.

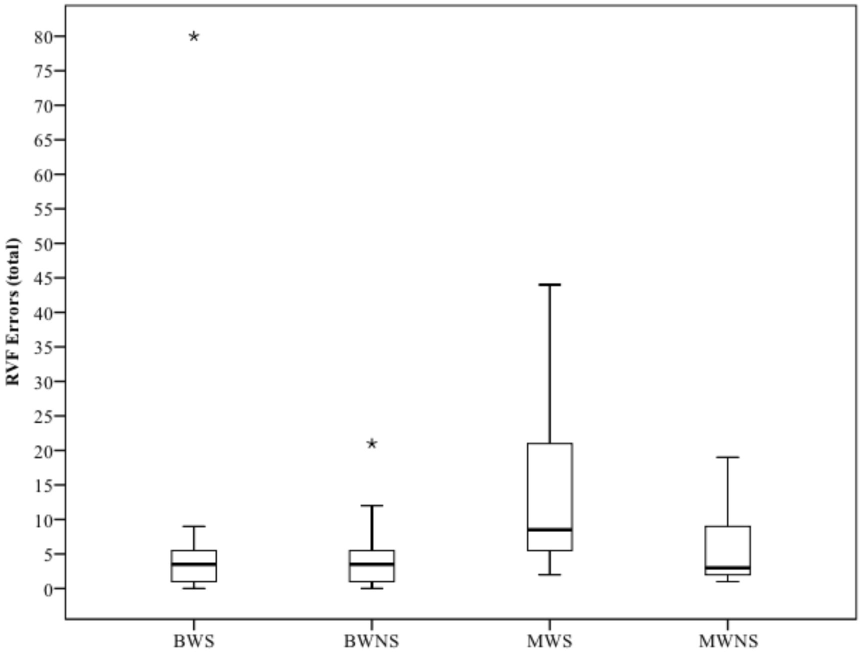

Figure 17. Median score, interquartiles, and range for the RVF error condition. Note: * = extreme outliers.

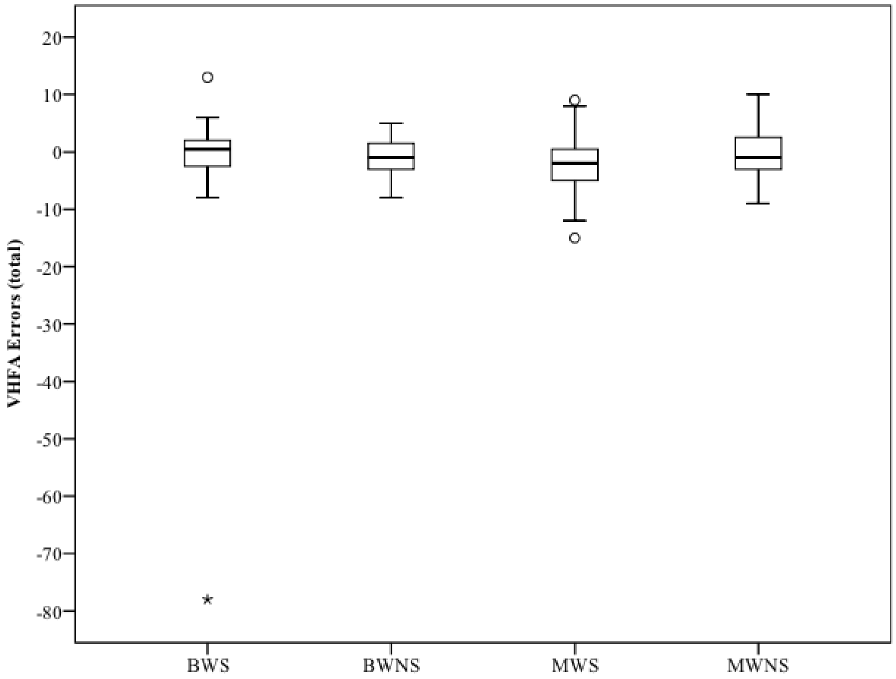

Figure 18. Median score, interquartiles, and range for the VHFA error condition. Formula: $LI_{(VHF)}$ = (E_LVF) – (E_RVF). Negative values = LVF advantage; Positive values = RVF advantage. Note: ° = outliers; * = extreme outliers.

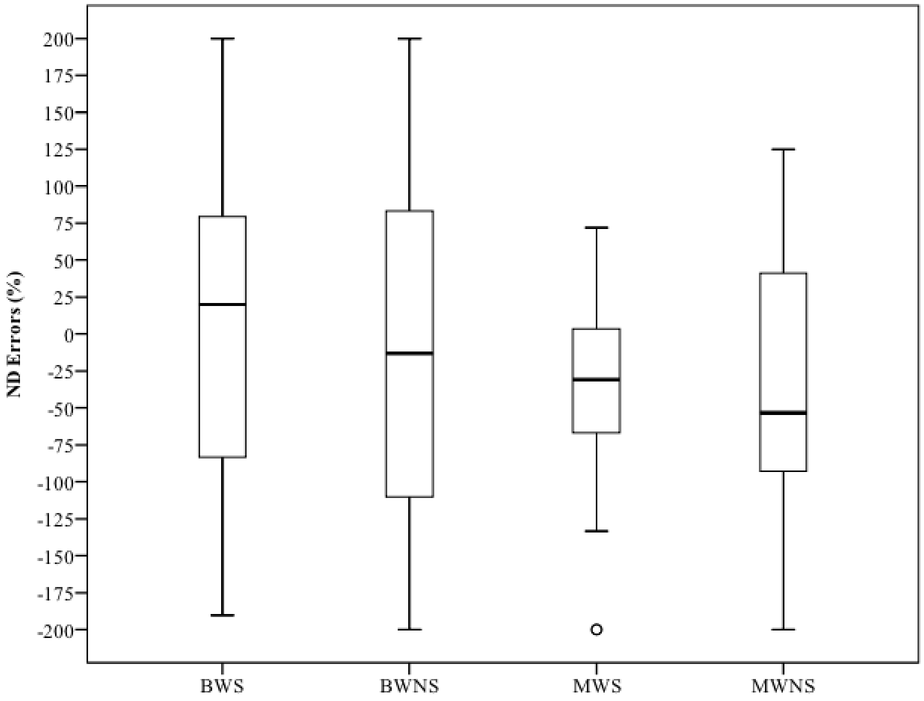

Figure 19. Median score, interquartiles, and range for the ND error condition. Note: ° = outliers.

4.3 Dual-Task Paradigm

The individual participant scores for the (1) PCS-RL, (2) PCS-RR, (3) PCS-CL, (4) PCS-CR conditions can be found in Appendix 10. The group results for each of the four participant groups are listed in Tables 6 and 7 and displayed in Figures 20 to 23 as box and whisker plots. The effect size is reported for all significant findings using the Hodges-Lehmann estimator.

4.3.1 Group Differences

BWS vs. MWS

The PCS-CR was lower in BWS (*Mdn* = 7%) than in MWS (*Mdn* = 25%), p = .004, with a Hodges-Lehman median difference of -19% (95% CI = -39% to -6%). No significant differences were found between groups for the PCS-RL (p = .429), PCS-RR (p = .114), and PCS-CL (p = .565) conditions.

BWS vs. BWNS

No significant differences were found between groups for the PCS-RL (p = .091), PCS-RR (p = .265), PCS-CL (p = .174), and PCS-CR (p = .289) conditions.

MWS vs. MWNS

The PCS-CR was higher in MWS (*Mdn* = 25%) than in MWNS (*Mdn* = 5%), p = .012, with a Hodges-Lehman median difference of 16% (95% CI = 3% to 34%). No significant differences were found between groups for the PCS-RL (p = 1.000), PCS-RR (p = .242), and PCS-CL (p = .383) conditions.

BWNS vs. MWNS

The PCS-RL was lower in BWNS (*Mdn* = 4%) than in MWNS (*Mdn* = 9%), p = .014, with a Hodges-Lehman median difference of -7% (95% CI = -29% to -1%). No significant differences were found between groups for the PCS-RR (p = .201), PCS-CL (p = .414), and PCS-CR (p = .495) conditions.

4.3.2 Task Differences

PCS-RL vs. PCS-RR

No significant differences in tapping rate were found between the PCS-RL and PCS-RR conditions for BWS (p = .794), BWNS (p = .179), MWS (p = .370), or MWNS (p = .823).

PCS-CL vs. PCS-CR

For MWS, the tapping rate was lower for the PCS-CL (*Mdn* = 15%) than PCS-CR (*Mdn* = 25%) condition, p = .028, with a Hodges-Lehman median difference of 10% (95% CI = 1% to 29%). No significant differences in tapping rate were found between the PCS-CL and PCS-CR conditions for BWS (p = .179), BWNS (p = .332), or MWNS (p = .526).

PCS-RL vs. PCS-CL

No significant differences in tapping rate were found between the PCS-RL and and PCS-CL conditions for BWS (p = .654), BWNS (p = .247), MWS (p = .823), or MWNS (p = .627).

PCS-RR vs. PCS-CR

No significant differences in tapping rate were found between the PCS-RR and PCS-CR conditions for BWS (p = .079), BWNS (p = .247), MWS (p = .218), MWNS (p = .391).

Table 6. *Dual-Task Results for the BWS and BWNS Groups.*

	BWS				BWNS			
	PCS-RL (%)	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**	**PCS-RL (%)**	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**
Mean	9	10	15	8	3	6	8	12
SD	16	12	19	17	14	7	15	15
Median	10	14	9	7	4	6	5	8
Range	-22 – 59	-14 – 35	-5 – 81	-12 – 67	-26 – 42	-14 – 23	-15 – 5	-20 – 41

Note. ***PCS-RL:*** Percent Change Score – Reading/Finger-Tapping with Left Hand; ***PCS-RR:*** Percent Change Score – Reading/Finger-Tapping with Right Hand; ***PCS-CL:*** Percent Change Score – Counting/Finger-Tapping with Left Hand; ***PCS-CR:*** Percent Change Score – Counting/Finger-Tapping with Right Hand

Table 7. *Dual-Task Results for the MWS and MWNS Groups.*

	MWS				MWNS			
	PCS-RL (%)	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**	**PCS-RL (%)**	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**
Mean	13	21	14	33	20	18	14	13
SD	38	24	42	28	32	34	30	25
Median	11	17	15	25	9	11	5	5
Range	-102 – 81	-15 – 80	-118 – 71	-1 – 88	-39 – 90	-54 – 91	-41 – 91	-22 – 80

Note. ***PCS-RL:*** Percent Change Score – Reading/Finger-Tapping with Left Hand; ***PCS-RR:*** Percent Change Score – Reading/Finger-Tapping with Right Hand; ***PCS-CL:*** Percent Change Score – Counting/Finger-Tapping with Left Hand; ***PCS-CR:*** Percent Change Score – Counting/Finger-Tapping with Right Hand

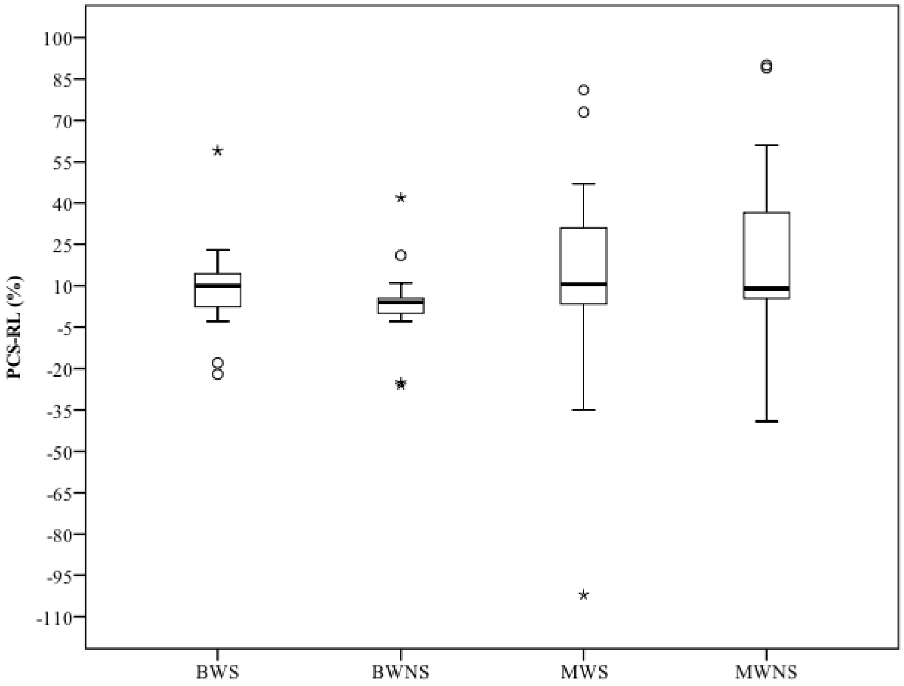

Figure 20. Median score, interquartiles, and range for the PCS-RL condition. Note: ° = outliers; * = extreme outliers.

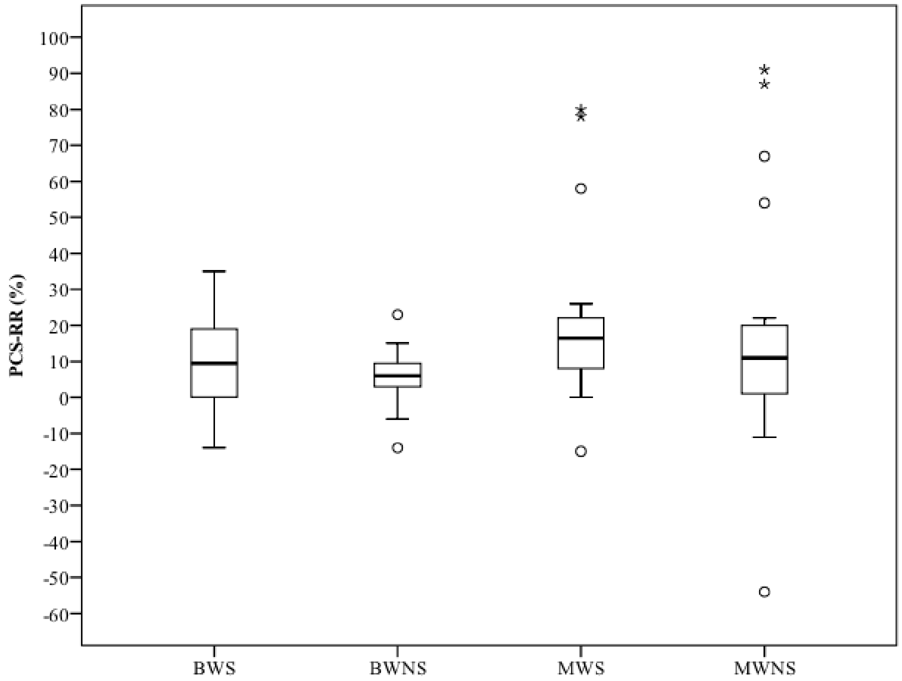

Figure 21. Median score, interquartiles, and range for the PCS-RR condition. Note: ° = outliers; * = extreme outliers.

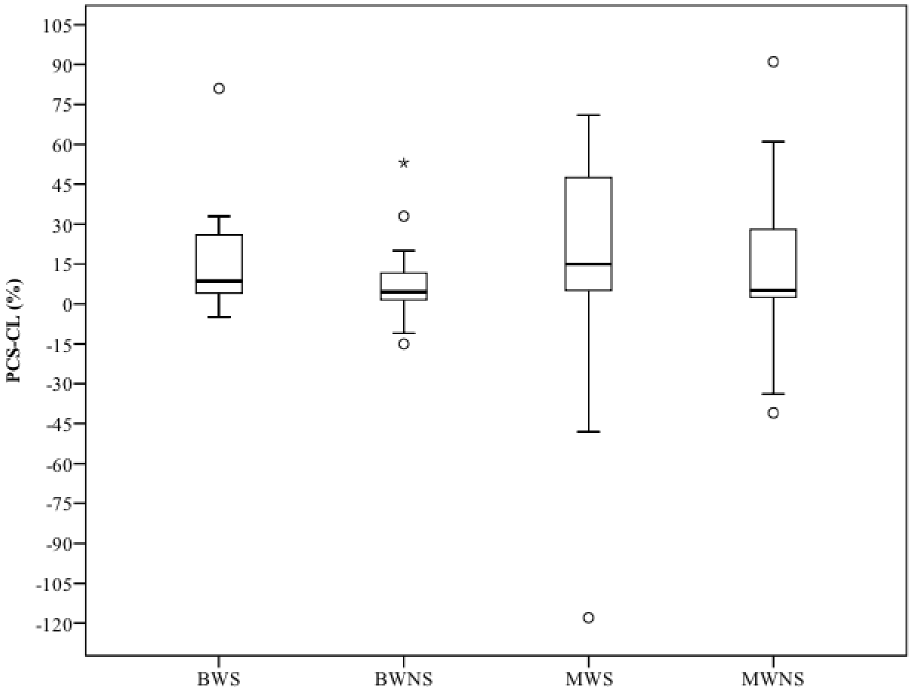

Figure 22. Median score, interquartiles, and range for the PCS-CL condition. Note: ° = outliers; * = extreme outliers.

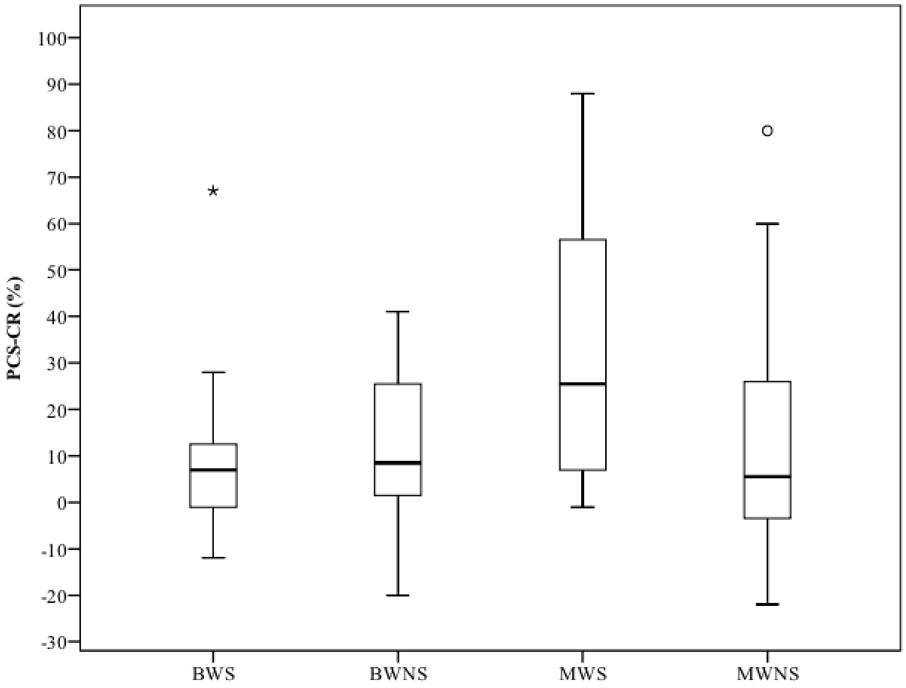

Figure 23. Median score, interquartiles, and range for the PCS-CR condition. Note: ° = outliers; * = extreme outliers.

4.4 Statistical Relationships

Spearman rank-order correlation coefficients (r_s) were computed to ascertain the relationship among the tasks and stuttering severity, as well as language modalities. Alpha levels of .05 were used (2-sided). Table 8 shows all bivariate correlations and indicates those significant at the .01 and .05 level.

Dichotic Listening Paradigm

Stuttering severity was not significantly correlated with the L=R and IID conditions. In addition, none of the four language modalities (listening, speaking, reading, and writing) were significantly correlated with the L = R and IID conditions.

Visual Hemifield Paradigm

Stuttering severity was not significantly correlated with any of the reaction time and error rate conditions. For the reaction time conditions, all four language modalities were significantly negatively correlated with LVF reaction time (r_s = -.40, -.42, -.42, -.41 respectively, $p < .01$) and RVF reaction time conditions (r_s = -.38, -.39, -.39, -.38 respectively, $p < .01$). For the error rate conditions, all four language modalities were significantly negatively correlated with the RVF errors condition (r_s = -.31, -.29, -.32, -.30 respectively, $p < .01$). In contrast, only the listening and reading modalities were significantly positively correlated with the ND for errors condition (r_s = .25, .24 respectively, $p < .05$), whereas the speaking and writing modalities were not significantly correlated with the ND for errors condition.

Dual-Task Paradigm

There was a significant positive correlation between stuttering severity and the PCS-CL condition ($r_s = .33$, $p < .05$). Stuttering severity was not significantly correlated with the PCS-RL, PCS-RR, and PCS-CR conditions. In contrast, all of the four language modalities were significantly negatively correlated with the PCS-RL (r_s = -.30, -.28, -.30, -.30 respectively, $p < .05$), PCS-RR (r_s = -.28, -.27, -.29, -.26 respectively, $p < .05$), and PCS-CR conditions (r_s = -.29, -.28, -.32, -.27 respectively, $p < .05$). There was no significant correlation with the PCS-CL condition.

Table 8. *Bivariate Correlations.*

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. LHQ Listening	1.00																			
2. LHQ Speaking	.97**	1.00																		
3. LHQ Reading	.98**	.97**	1.00																	
4. LHQ-Writing	.97**	.99**	.97**	1.00																
5. Stutter Severity	-.17	-.26	-.15	-.26	1.00															
6. Stutter Anxiety	-.18	-.21	-.21	-.20	.47**	1.00														
7. L=R	.08	.08	.10	.08	-.19	.10	1.00													
8. IID	-.19	-.17	-.22	-.16	.03	.25	.34**	1.00												
9. LVF (RT)	-.40**	-.42**	-.42**	-.41**	-.11	.13	-.08	.07	1.00											
10. RVF (RT)	-.38**	-.39**	-.39**	-.38**	-.06	.10	-.03	.09	.92**	1.00										
11. VHFA (RT)	.02	-.03	-.01	-.04	.15	.08	-.21	.02	.13	-.23*	1.00									
12. ND (RT)	-.01	-.06	-.04	-.07	.11	.09	-.21	.04	.19	-.17	.99**	1.00								
13. LVF (Errors)	-.16	-.18	-.19	-.20	.24	-.05	-.28*	-.06	.32**	.40**	-.13	-.13	1.00							
14. RVF (Errors)	-.31**	-.29**	-.32**	-.30**	.04	-.03	-.18	-.20	.33**	.44**	-.24*	-.23*	.63**	1.00						
15. VHFA (Errors)	.14	.10	.13	.09	.20	-.02	-.02	.07	.08	.04	.14	.15	.31**	-.39**	1.00					
16. ND (Errors)	.25*	.21	.24*	.20	.11	-.17	-.19	.08	.10	.08	.10	.10	.53**	-.26*	.81**	1.00				
17. PCS-RL	-.30**	-.28*	-.30**	-.30**	.13	.06	-.01	.11	.27*	.27*	.03	.05	.06	.11	.00	-.10	1.00			
18. PCS-RR	-.28*	-.27*	-.29**	-.26*	.01	.03	-.03	-.01	.31**	.33**	-.04	-.03	.03	.24*	-.13	-.21	.32**	1.00		
19. PCS-CL	-.18	-.16	-.20	-.17	.33*	.32*	-.04	.12	.17	.24*	-.23*	-.21	.16	.11	.08	.06	.51**	.13	1.00	
20. PCS-CR	-.29**	-.28*	-.32**	-.27*	.12	.13	-.17	-.05	.40**	.49**	-.25*	-.21	.44**	.45**	-.00	.06	.20	.48**	.35**	1.00

Note. ***LHQ:*** Language History Questionnaire for Listening, Speaking, Reading, and Writing (English Language); ***Stuttering Severity:*** Rating Scale (German Language); ***Stutter Anxiety:*** Rating Scale (German Language); ***L=R:*** Equal Interaural Intensity Difference for the left and right ear; ***IID:*** Interaural Intensity Difference; 'cross-over point'; ***PCS-RL:*** Percent Change Score – Reading/Finger-Tapping with Left Hand; ***PCS-RR:*** Percent Change Score – Reading/Finger-Tapping with Right Hand; ***PCS-CL:*** Percent Change Score – Counting/Finger-Tapping with Left Hand; ***PCS-CR:*** Percent Change Score – Counting/Finger-Tapping with Right Hand; ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference; ***RT:*** Reaction Time.

* Correlation is significant at the .05 level (2-tailed); ** Correlation is significant at the .01 level (2-tailed).

4.5 Summary of Results

Dichotic Listening Paradigm

(1) All four participant groups were found to have a REA but there were no significant differences between any of the groups on the L=R and IID conditions.

Visual Hemifield Paradigm

(1) Although all four participant groups exhibited a LVF advantage, no significant differences were found between any of the groups in regard to VHF advantage and ND reaction times and error rates.

(2) The BWS group demonstrated faster reaction times and fewer errors for both LVF and RVF conditions compared to the MWS group. However, no such differences were found between the BWS and BWNS groups.

(3) There were no significant differences between the MWS and MWNS groups for the LVF and RVF reaction times. However, the MWNS group showed slower LVF and RVF reaction times compared to the BWNS group.

(4) The MWS group demonstrated more errors than MWNS for the RVF but no differences were found for LVF. In addition, the MWNS group did not differ from the BWNS group on LVF and RVF error rates.

Dual-Task Paradigm

(1) Compared to the MWS group, the BWS group demonstrated lower tapping rate disruption on the PCS-CR condition. The groups did not differ in the performance on the PCS-RL, PCS-RR, and PCS-CL conditions.

(2) The BWS and BWNS groups did not differ in their performance on any of the counting or reading dual-task conditions.

(3) The MWS group exhibited a higher tapping rate disruption than the MWNS group in the PCS-CR condition. The groups did not differ on any of the other conditions.

(4) The BWNS group demonstrated lower tapping rate disruption than MWNS in the PCS-RL condition. The groups did not differ on any of the other conditions.

(5) No significant differences were found between most of the task conditions for any of the participant groups. The exception was for the MWS group, which demonstrated a lower tapping rate disruption in the PCS-CL condition than in the PCS-CR condition.

Statistical Relationships

(1) Stuttering severity was not significantly correlated with any of the results obtained for the dichotic listening and visual hemifield testing. It was found to be correlated with one of the dual-task conditions - PCS-CL.

(2) The proficiency rankings of the language modalities (listening, speaking, reading, writing) were not significantly correlated with the dichotic listening results. However, the proficiency rankings were correlated with various results obtained for the visual hemifield and dual-task tests. All four modalities were negatively correlated with the reaction time LVF, reaction time RVF, and errors RVF conditions. Each of the language modalities were also negatively correlated with the PCS-RL, PCS-RR, and PCS-CR conditions.

5. Discussion

This study explored language processing in BWS and MWS with regard to hemispheric asymmetry. Comparisons were made between 20 BWS, 20 MWS, 20 BWNS, and 20 MWNS on measures of (a) dichotic listening, (b) visual hemifield testing, and (c) a dual-task paradigm. In addition, relationships between the different measures, as well as stuttering severity and language modalities (listening, speaking, reading, writing) were examined. The aim was to identify if differences exist between the four participant groups and to explore the relationship between stuttering and bilingualism. Specifically, it was hypothesised that (1) BWS would have greater left-hemisphere dominance for cerebral processing over MWS, (2) BWS would have greater right-hemisphere dominance for cerebral processing over BWNS, (3) MWS would have greater right-hemisphere dominance for cerebral processing over MWNS, and (4) BWNS would have greater left-hemisphere dominance for cerebral processing over MWNS.

5.1 Dichotic Listening Paradigm

A dichotic listening task was chosen to investigate hemispheric asymmetry differences in auditory processing of speech stimuli between the four groups using an undirected attention task. The dichotic listening paradigm in this study involved manipulation of the IID of CV stimuli presented to the left and right ear. The results indicated a REA for the processing of CV stimuli across the four groups on the L=R task. Results from the IID task indicated that all groups crossed over to a LEA when the stimulus presented to the right ear was still louder than the stimulus presented to the left ear. One important finding of this study was that no significant differences were observed between the participant groups for both the L=R and IID conditions. Furthermore, neither stuttering severity nor the proficiency rankings of the language modalities (listening, speaking, reading, writing) were significantly correlated with any of the dichotic listening results. The discussion for the dichotic listening paradigm is organised according to three sections. The first two sections compare the present results to past research in the areas of (1) developmental stuttering, and (2) bilingualism. The third section provides a combined discussion of the overall results according to stuttering and bilingualism.

5.1.1 Developmental Stuttering

***<u>Hypothesis 1:</u>* MWS will have significantly greater right-hemisphere dominance than MWNS on a dichotic listening paradigm.**

Functional hemispheric differences for speech processing have been studied for decades using dichotic listening paradigms. The typical testing approach is based on binaural presentation of CV stimuli at an equal loudness level (L=R). A REA is often observed, which is assumed to reflect left hemisphere dominance for language (Hugdahl, 2011a; Kimura, 1961). However, the results of various studies assessing dichotic listening in PWS have yielded mixed results with some studies indicating a REA similar to PWNS, while others have found either no ear advantage or a LEA. For example, Foundas et al. (2004) used a L=R condition and found left-handed male AWS to show a LEA and right-handed female AWS to show no ear advantage on a nondirected verbal listening task. Blood and Blood (1989a) also used a L=R condition and reported a significant difference in dichotic listening between AWS and AWNS with respect to the strength of the ear advantage. The AWS presented with a weaker REA compared to AWNS. They found no significant differences between male and female AWS.

There are a number of studies indicating no differences between PWS and PWNS (Andrews, Sorby, & Quinn, 1972; Brosch et al., 1999; Dorman & Porter, 1975; Gruber & Powell, 1974; Pinsky & McAdam, 1980). For example, Dorman and Porter (1975) examined hemispheric lateralisation for speech processing in PWS. They compared right-handed AWS, presenting with a moderate to severe stutter, to a comparison group of AWNS. The study revealed a REA for both male and female AWS with a similar magnitude to the REA found in AWNS. These results have also been confirmed in a more recent study assessing CWS, which suggested that the majority of the children (CWS & CWNS) showed a REA (Brosch et al., 1999). The present results based on the L=R condition would appear to agree with the collection of studies finding a REA for both PWS and PWNS participants. However, no significant differences were found between groups.

The use of an IID condition to evaluate dichotic listening provided a more sophisticated (and presumably more sensitive) way to estimate hemispheric laterality for speech processing.

Hugdahl et al. (2008) were the first to examine dichotic listing using a IID condition. Based on examination of right-handed PWNS, they found that their participants maintained a REA even though the intensity in the left ear was higher than the right ear. More specifically, the participants showed a REA resistance until the -9 dB IID point, at which time there was a shift to a LEA. The only previously reported study to examine IID in PWS was by Robb et al. (2013) and their results paralleled those of Hugdahl (2008). These researchers found that PWNS crossed at an IID of -12 dB, which means that a shift from a REA to a LEA was not evident until the CV stimuli were still 12 dB more intense in the left ear. In contrast, the PWS group crossed over to a LEA at an IID of 6 dB.

The results from the present group of PWS (MWS and BWS) are contrary to those of Hugdahl et al. (2008) and Robb et al. (2013). There was considerable variability in performance found for the PWS groups. High variability was also observed for the PWNS (MWNS and BWNS) groups. There was a general tendency for both the PWS and PWNS groups to shift from a REA to LEA while there was still a louder signal in the right ear. Although MWS crossed over to a LEA at an earlier point (18 dB) compared to the MWNS group (11 dB), the difference between groups was not significant. A REA resistance due to left hemisphere dominance for speech processing, as proposed earlier by these researchers, was not reflected in the current findings. Therefore, hypothesis 1 was rejected. There are several factors which might explain the lack of difference between participant groups, including sex differences, psychoacoustic influences, and methodological issues. These factors will be discussed in detail in Section 5.1.3, which provides a combined discussion for all four groups.

5.1.2 Bilingualism

Hypothesis 2: ***BWNS will have significantly greater left-hemisphere dominance than MWNS on a dichotic listening paradigm.***

Hull and Vaid (2007) conducted a meta-analysis of 66 behavioural studies examining cerebral hemispheric language lateralisation in bilingual individuals. The age of onset of bilingualism was found to be the most influential factor, with simultaneous bilinguals demonstrating bilateral hemispheric involvement and sequential bilinguals showing left hemisphere dominance.

Interestingly, these researchers suggested that the contribution of the left hemisphere was even greater among the sequential bilinguals who were less proficient in their second language. The conclusions reached by Hull and Vaid (2007) were considered in the present study and in the interpretation of past research. Presumably, sequential bilinguals would be expected to show a robust REA as a result of learning a second language later in life (compared to a simultaneous bilingual).

Functional hemispheric differences for language processing have been studied in bilinguals using dichotic listening paradigms. Bilinguals have been found to demonstrate atypical results on dichotic listening tasks (Fabbro et al., 1991; Hull & Vaid, 2006, 2007; Ke, 1992; Soveri et al., 2011). For example, Ke (1992) examined a group of sequential English-Chinese bilinguals compared to monolingual English speakers and observed no ear advantage in the bilinguals for either L1 or L2. Alternatively, D'Anselmo et al. (2013) examined sequential bilinguals speaking either German or Italian as L1 and English as L2 on a dichotic listening paradigm. These researchers found that although all participants showed a REA while processing their native language, German native speakers demonstrated a stronger REA than Italian native speakers during English language processing.

Comparison of the L=R dichotic listening performance in the MWNS and BWNS groups in the present study found no significant difference between groups. The REA appeared to be slightly less robust in BWNS (8%) compared to MWNS (20%). Based on the results of the IID condition, the MWNS group was found to cross-over from a REA to a LEA at 11dB; while the BWNS group crossed at an IID of 8 dB. That is, a shift from a REA to a LEA was already evident when the CV stimuli were still 11 dB (MWNS) and 8 dB (BWNS) more intense in the right ear. Although the BWNS appeared to hold on to the REA slightly longer than the MWNS, the difference between these two groups was minor and not significant. The combined results for the dichotic listening paradigm would suggest a negligible difference between MWNS and BWNS in the auditory processing of language. Therefore, hypothesis 2 was rejected. The various factors which might explain the lack of difference between the MWNS and BWNS groups are discussed below.

5.1.3 Stuttering and Bilingualism

***<u>Hypothesis 3:</u>* BWS will have significantly greater left-hemisphere dominance than MWS on a dichotic listening paradigm.**

***<u>Hypothesis 4:</u>* BWS will have significantly greater right-hemisphere dominance than BWNS on a dichotic listening paradigm.**

The results from the dichotic listening paradigm provided no evidence of language lateralisation differences between participant groups. Accordingly, hypotheses 3 and 4 were rejected. Several possibilities are presented to account for the lack of difference between groups. Foundas et al. (2004) previously reported sex differences in dichotic listening performance between right-handed male and female PWS. Specifically, females were found to show no ear advantage, while males showed a typical REA. Among the 80 participants in the present study, all of whom where right-handed, there were 48 males and 32 females, which were balanced in each group (12 males, 8 females). Based on the results obtained in the L=R condition, 40 males showed an REA (83%) and 8 males showed and LEA (17%), whereas 26 females showed an REA (81%) and 6 females showed and LEA (19%). Thus, the similar performance between males and females would seem to discount the notion of a sex-based influence on the present results. It is also worth noting that a recent meta-analysis on sex differences in dichotic listening found only a minor difference between men and women with a very small effect size (Voyer, 2011).

The possible influence of the psychoacoustic phenomenon known as the ‘just noticeable difference’ (JND) was also considered in regard to the present results. The JND refers to the threshold required for a change in frequency or loudness to be perceived (Rowland & Tobias, 1967). Research has shown that the JND becomes smaller if two stimuli are played simultaneously, such as in a dichotic listening task (Shub, Durlach, & Colburn, 2008). Hence, the IID between the left and right ear used in the present study may have been within a range that was difficult to discriminate, thereby contributing to considerable variability in performance. However, Yost and Dye (1988) found that an IID of 1 dB can be detected across a wide range of frequencies. In the present study, the IID varied by increments of 3 dB, therefore it seems unlikely there was a JND influence on participant performance.

The dichotic listening paradigm used in this study was time consuming, requiring approximately 30 minutes to complete. The test involved dedicated concentration. As a result, some participants might have experienced a decrease in concentration, whereas others might have attended to one ear more than the other regardless of the task being undirected. A number of participants anecdotally reported having perceived stimuli presented to the right ear but not the left ear. Although the undirected dichotic listening task used in the present study was designed to be a bottom-up condition, it might have turned into a top-down condition. Bottom-up processing involves a bias for the right ear due to the left hemispheric dominance for processing speech, whereas top-down processing involves directed attention to either the left or right ear (Westerhausen & Hugdahl, 2008). This aligns with findings by Westerhausen et al. (2009) which showed a significant bottom-up and top-down interaction regarding the modulation of the ear advantage. They suggested that bottom-up and top-down attention manipulations should be considered as interacting rather than independent factors with respect to IID conditions in dichotic listening tasks (Westerhausen et al., 2009).

It should also be noted that, despite differences being found in various studies between PWS and PWNS or bilinguals and monolinguals, these past findings may be a reflection of the method of data analysis. Blood and Blood (1989b) investigated this topic by comparing 10 MWS and 10 MWNS on a dichotic listening paradigm and using five different data analysis methods previously reported in the literature. Interestingly, it was found that the ear advantage changed in 8 out of the 20 participants as a result of the data analysis employed. That is, the statistical significance between the two participant groups was dependent upon the choice of data analysis rather than the data obtained from the participants. This finding confirms reviews by Paradis (1990, 1992, 2003, 2008), who questioned not only the claim of differences in language lateralisation in bilinguals but also the use of behavioural tests of hemispheric asymmetry. According to Paradis (1990), the validity and reliability of behavioural tests of hemispheric asymmetry should be questioned, since many variables are reported to have an effect on the results (e.g., sex, handedness, language). He further argues that, given the substantial variability not only within and between individual participants but also groups of similar populations, it appears to be unlikely that experimental studies show lesser asymmetry of cerebral language processing. Having found an REA in all four of the present groups of participants, along with considerable intra-group variability, the current results would seem to support Paradis' (2003) claims.

A final factor to consider is the appropriateness of the method used in the present dichotic listening study. There are two different approaches to assessing hemispheric asymmetry for language processing: (1) behavioural measures and (2) neurophysiological measures (Hugdahl, 2011a). The present study implemented a behavioural measure (i.e., dichotic listening) using traditional CV syllables as stimuli. While the L=R condition of the dichotic listening paradigm might have appeared to be sensitive to detect an REA as typically found in various populations, the IID condition failed to detect any group differences in the magnitude of the REA. Thus, behavioural tests like dichotic listening may not be an appropriate testing tool for some populations.

It is important to note that neurophysiological measures have provided evidence for incomplete left-laterality in PWS with respect to language processing and production (Beal et al., 2007; Biermann-Ruben et al., 2005; Blomgren et al., 2003; Braun et al., 1997; De Nil et al., 2008; Foundas et al., 2003; Fox et al., 2000; Neumann et al., 2003; Salmelin et al., 2000; Van Borsel et al., 2003). The same is applicable for studies investigating brain differences in simultaneous and sequential bilinguals (Indefrey, 2006; Kovelman et al., 2008; Mechelli et al., 2004). Interestingly, all of the aforementioned studies have used neuroimaging instead of behavioural tests as their method of choice. For instance, Beal et al. (2007) used voxel-based morphometry to assess neuroanatomical differences in speech-related cortex between PWS and PWNS. Significant differences in localised grey matter and white matter densities were found for the left and right hemispheric regions, which are involved in auditory processing. Some of the differences in bilateral grey matter density were noticed in the superior temporal gyrus, indicating a greater increase in the right hemisphere in comparison with the left hemisphere in AWS. Further differences included Brodmann area 44 in the inferior frontal lobe, with (a) increased grey matter density in the left hemisphere, and (b) increased white matter density in the right hemisphere.

Behavioural tests of hemispheric asymmetry based on CV processing may not be suitable to identify some of the differences in brain function and, consequently, may not be appropriate to use for the assessment of certain populations like PWS and bilinguals. This suggestion is supported by the recent work of Westerhausen, Kompus, and Hugdahl (2014), mapping hemispheric symmetries, relative asymmetries and absolute asymmetries underlying the auditory laterality effect. In total, 104 healthy, right-handed male and female participants were assessed on hemispheric differences underlying dichotic listening performance. All participants were native Norwegian speakers but no information was provided regarding other languages spoken. Hence, it cannot be ruled out that this was also reflected in the findings of the study. The results were analysed using behavioural data and functional imaging data (fMRI). For the behavioural data, a significant REA was found. These results are comparable to the findings of the L=R condition for the MWNS in the present study. Interestingly, for the functional imaging data, it was found that (a) superior temporal, lateral, and medial frontal and inferior parietal regions were activated symmetrically, and (b) asymmetries were mainly found in temporal and frontal regions biased towards the left hemisphere, but also indicating a few right-dominant regions. Therefore, it was suggested that a bi-hemispheric cortical network, with a symmetrical and mostly leftward asymmetrical pattern, was activated during dichotic listening. It would seem that neuroimaging tests that examine inter-hemisheric differences in language processing in different participant groups, such as BWS, BWNS, MWS, MWNS, may be a more useful tool to analyse the degree of lateralisation.

5.2 Visual Hemifield Paradigm

A visual hemifield paradigm was chosen to assess hemispheric asymmetry in the four groups of participants. The paradigm used in the present research involved bilateral presentation of two contrasting visual stimuli to the LVF and RVF. For the reaction time conditions (VHF advantage and ND), results indicated a LVF advantage across all groups. For the error rate conditions (VHF advantage and ND), results indicated a LVF advantage for the MWS, MWNS, and BWNS groups, and a RVF advantage for the BWS group. No significant differences were found between any of the four participant groups for the reaction time and error rate conditions (VHF advantage and ND). In addition, no significant correlation was found between stuttering severity and reaction times or errors. However, all four language modalities were significantly negatively correlated with reaction times for the LVF and RVF as well as RVF errors. That is, participants who rated themselves as highly proficient speakers of English also demonstrated faster reaction times and fewer errors.

5.2.1 Developmental Stuttering

***<u>Hypothesis 1:</u>* MWS will have significantly greater right-hemisphere dominance than MWNS on a visual hemifield paradigm.**

Visual hemifield paradigms provide an alternative way to assess functional hemispheric differences for language processing. Although less common than dichotic listening, both approaches involve simultaneous presentation of two contrasting stimuli. Both approaches tend to be confined to right-handed participants, so as to ensure a left hemisphere dominance for the processing of language-related stimuli. A RVF advantage is presumed to reflect dominance of the left hemisphere for language processing (Springer & Deutsch, 1998).

Research applying a visual hemifield paradigm to PWS has yielded mixed results in regard to hemispheric dominance for language processing (Rami et al., 2000; Rastatter & Dell, 1987b; Rastatter & Stuart, 1995; Szelag et al., 1993; Szelag et al., 1997). Some studies have found a LVF advantage for children with severe stuttering (Szelag et al., 1993), while others suggested a LVF advantage only for ‘highly neurotic’ CWS regardless of stuttering severity (Szelag et al., 1997). It has further been suggested that cerebral dominance for language is influenced by the particular words used in a visual hemifield paradigm (Rastatter & Dell, 1987b; Rastatter, Dell, McGuire, & Loren, 1987). For example, Rastatter and Dell (1987b) found a difference in VHF advantage depending on whether the pictures displayed represented either concrete or abstract words. The right hemisphere (LVF) was superior for the processing of concrete words in both AWS and AWNS using reaction time as a measure. On the other hand, there has also been research suggesting left hemisphere dominance (RVF) for the processing of lexical stimuli in both CWS (Hardin et al., 1992) and AWS (Rami et al., 2000). For example, Rami et al. (2000) assessed vocal reaction times to unilaterally presented high and low frequency verbs in AWS and found left hemispheric dominance for the processing of lexical items similar to those of AWNS.

Concrete words were used as visual stimuli in the present study. Based on the results of the reaction time measures (VHF advantage and ND), it would appear that the current findings agree with the research conducted by Rastatter and Dell (1987b), since all four participant groups demonstrated a LVF advantage. That is, all participant groups exhibited faster reaction time when stimuli were presented to the LVF, indicating that the right hemisphere was more efficient processing the visual stimuli. The same effect was observed for the MWS and MWNS groups in regard to error rate. These participants displayed fewer errors when stimuli were presented to the LVF. MWS showed the greatest LVF advantage in the error rate condition. Similar to the dichotic listening paradigm, considerable variability in performance was found on the visual hemifield paradigm for all participant groups. However, MWS performed very similar to MWNS on the VHF advantage and the ND conditions for both reaction time and error rate. Based on these findings, MWS did not have greater right-hemisphere dominance than MWNS. Thus, hypothesis 1 was rejected. There are several factors which might explain the lack of difference between participant groups, including differences in hemispheric specialisation as well as methodological differences. These factors are discussed in detail in Section 5.2.3.

5.2.2 Bilingualism

Hypothesis 2: ***BWNS will have significantly greater left-hemisphere dominance than MWNS on a visual hemifield paradigm.***

Sequential bilinguals were originally expected to show a strong RVF advantage as a result of a greater reliance on the left hemisphere compared to monolinguals (Hull & Vaid, 2007). Past studies have found a robust RVF advantage for sequential bilinguals, indicating left hemispheric processing (Beaton et al., 2007; Peng & Wang, 2011; Vaid, 1987). For example, findings by Vaid (1987) suggested that the RVF advantage was more pronounced in sequential bilinguals compared to monolinguals, as well as simultaneous bilinguals. However, this suggestion is weakened somewhat by the findings of Beaton et al. (2007) who assessed simultaneous and sequential bilinguals and found all participants to demonstrate a comparable RVF advantage.

The present results are not in agreement with previous studies examining bilingual groups. No significant difference between the BWNS and MWNS groups were found. Both monolinguals and bilinguals were found to exhibit a LVF advantage for processing of visual stimuli. These findings align with the results of Rastatter and Dell (1987b), who suggested a LVF advantage for concrete words. Therefore, BWNS did not have greater left-hemisphere dominance than MWNS and hypothesis 2 was rejected. The various factors which might explain the lack of difference between the monolingual and bilingual groups are discussed below.

5.2.3 Stuttering and Bilingualism

Hypothesis 3: ***BWS will have significantly greater left-hemisphere dominance than MWS on a visual hemifield paradigm.***

Hypothesis 4: ***BWS will have significantly greater right-hemisphere dominance than BWNS on a visual hemifield paradigm.***

The results from the visual hemifield paradigm provided no evidence of group differences for any of the laterality measures. Accordingly, hypotheses 3 and 4 were rejected. A LVF advantage was observed for both the reaction time and error rate measures across all four speaker groups, except for the BWS group on the error rate condition. All of the participants generally showed faster reaction times and fewer errors for stimuli presented to the LVF. Alternatively they took longer and made more errors when stimuli were presented to the RVF. The current data appear to point to superior processing capabilities of the right hemisphere over the left with respect to visual stimuli. Several possibilities are presented for the lack of difference between participant groups. Findings of the present study seem to be consistent with previous research suggesting a greater facilitation for concrete words in the right hemisphere (Rastatter & Dell, 1987b; Rastatter, Dell, et al., 1987; Shibahara & Wagoner, 2002). Rastatter et al. (1987) found that reaction times were faster when concrete stimuli were presented to the LVF, whereas abstract stimuli were processed faster when presented to the RVF. This pattern has been noted in both PWS (Rastatter & Dell, 1987b) and PWNS (Shibahara & Wagoner, 2002) and indicates that language organisation might also be lexically dependent. Each hemisphere holds some level of linguistic competence and performance for certain types of linguistic information. Nevertheless, these results should be viewed with caution, especially in the light of a study by Fiebach and Friederici (2004), which provided fMRI evidence against a specific right hemisphere involvement in the processing of concrete words. More specifically, it was found that abstract words activated a subregion of the left inferior frontal gyrus (BA 45) more strongly than for concrete words, whereas concrete words were in particular associated with activity in the left basal temporal cortex.

The visual hemifield paradigm used in the present study was inspired by the work of Hunter and Brysbaert (2008). These researchers provided fMRI evidence that visual hemifield paradigms are a good measure of cerebral language dominance by directly assessing the validity of behavioural laterality measures and comparing them with fMRI brain imaging data. However, the present findings are not in agreement with the results obtained by these researchers. There are a number of methodological differences between the two studies that may account for the lack of agreement. One major difference between the two studies is the participants' handedness. The participants sampled by Hunter and Brysbaert were all left-handed, whereas the participants from the current study were all right-handed. Presumably, the majority of right-handed participants would naturally present with dominant left hemisphere language (Pujol, Deus, Losilla, & Capdevila, 1999). In contrast, atypical bilateral or right hemisphere language lateralisation has been found to occur more often in left-handed participants (Pujol et al., 1999). The current study also included four different speaker groups including PWS, whereas the former study only included one speaker group. However, the findings by Hunter and Brysbaert were not replicated with any of the four participant groups in the present study.

The current study also differed from Hunter and Brysbaert (2008) in regard to (a) stimuli presentation and (b) response collection. The present study was originally designed to present the visual stimuli for a duration of 200 ms, as done by Hunter and Brysbaert. However, a decision was made to reduce stimuli exposure to 100 ms based on pilot research, which found the task to be too easy for the participants (e.g., an absence of errors). Although Hunter and Brysbaert suggested that stimuli presentation of 200 ms was acceptable, Bourne (2006) recommended a reduction in maximum exposure to 150 ms. This reduction was based on the assumption that the shorter exposure time would decrease language processing, resulting in a greater number of errors. In the present study, there may have been a trade-off between language processing and number of errors as a result of using a 100 ms stimulus duration. The rapid presentation of the stimuli may have prevented strong language processing in the RVF, resulting in slower reaction time and a larger number of errors. Instead, the right hemisphere was more capable of processing the rapidly displayed visual stimuli, resulting in faster and more accurate responses.

Another major difference between the present study and that of Hunter and Brysbaert (2008) is in regard to the techniques for response collection. They used a vocal task, while the present study used a manual task. The reasons for the modified response collection in the present study were participant-based. Considering that half of the participants were PWS, and stuttering typically occurs on word onset or initial syllables of a word (Brown, 1945), a manual lexical decision response was thought to be most appropriate. This was done to avoid a distortion in the reaction time measure due to stuttering. One could argue that the change in methodology, with respect to the response collection, might have influenced the present results. However, several studies have found a strong RVF advantage, i.e., left hemisphere processing, for the recognition of printed words (Bub & Lewine, 1988; Chiarello, Nuding, & Pollock, 1988; Finkbeiner, Almeida, & Caramazza, 2006; Hunter & Brysbaert, 2008), which were used to collect the responses in the present study.

A further explanation for the LVF advantage demonstrated by the present groups might be attributed to the characteristics of the stimuli. The two cerebral hemispheres have been found to differ in their capacity to process information, with left hemisphere dominance for language processing and right hemisphere dominance for visuospatial processing and attention (Gotts et al., 2013; Hugdahl, 2011b, 2013; Wang, Buckner, & Liu, 2014). The early work by Semmes (1968) indicated that the left hemisphere was more specialised for focal representations, while the right hemisphere was more specialised for diffuse representations. This concept is further supported by Gotts et al. (2013) who found two distinct patterns of functional lateralisation in the brain, establishing that the left and right cerebral hemispheres have qualitatively different biases in how they interact with each other. These researchers demonstrated a preference of the left hemisphere to interact more exclusively with itself, whereas the right hemisphere showed a stronger tendency to interact with both hemispheres. These two different forms of interaction were associated with left-dominant functions (i.e., language) and right-dominant functions (i.e., visuospatial attention) (Gotts et al., 2013). The stimuli in the present study were visual and highly attention-demanding followed by a linguistic decision task (i.e., participants were required to promptly select the corresponding written word after the 100 ms picture presentation). As a result of this two-step procedure, the stimuli processing may have benefited more from the spatial connection of several synaptic inputs from both hemispheres and, thus, the integrative features of the right hemisphere provided a better and more effective match. This explanation is not only consistent with the fMRI data and proposal of Gotts et al. (2013) but also with a recent MEG study conducted by Doron, Bassett, and Gazzangia (2012), who concluded that interhemispheric interaction is greater when linguistic stimuli are presented to the right hemisphere instead of the language-dominant left hemisphere.

The current findings relate to other visual hemifield results supporting superior right hemispheric linguistic processing in PWS (Hand & Haynes, 1983; Rastatter & Dell, 1987b; Szelag et al., 1993; Szelag et al., 1997). However, some striking similarities between the PWS (BWS and MWS) and PWNS (BWNS and BWNS) participants were seen. That is, PWNS were also found to demonstrate right hemisphere superiority. Thus, the results are far from conclusive. More research is needed to further explore this issue of interhemispheric interaction, which may exist for linguistic and cognitive processing. Similar to the conclusions obtained for dichotic listening (see Section 5.1.4), neuroimaging tests might be more sensitive and a more suitable tool to identify hemispheric asymmetries in BWS.

5.2.4 Visual Hemifield Performance and Executive Functions

Executive functions refer to the management and control of complex cognitive processes, including inhibitory control, cognitive shifting, and updating of information (Jurado & Rosselli, 2007; Miyake et al., 2000). There is a considerable body of research examining executive functions across a variety of domains, including auditory, visual, and dual-tasks (Jurado & Rosselli, 2007; Miyake et al., 2000). Executive functions are thought to be mainly but not exclusively regulated by the prefrontal cortex (Alvarez & Emory, 2006; Moriguchi & Hiraki, 2013; Webb & Adler, 2008). The examination of executive functions provides another way to assess functional cerebral hemispheric processing differences in PWS. The analyses used for the reaction time and error conditions (VHF advantage and ND) examined performance in one hemisphere in relation to the other hemisphere to assess hemispheric asymmetry. In contrast, executive functions were estimated by examining performance of each hemisphere separately. Significant differences were found with respect to executive functions examining the reaction time and errors for the LVF and RVF individually. The results indicated faster reaction times and less errors for the bilingual participants (BWS, BWNS) compared to the monolingual participants (MWS, MWNS) regardless of stuttering. Moreover, it was found that MWS demonstrated more errors than any of the other groups.

Past researchers have found deficits in PWS in a number of executive function domains (Arnold & Obringer, 2014; Jones et al., 2012; Moore, 1986). Typically, PWS have been observed to demonstrate deficits in executive functions with regard to linguistic processing (Maxfield, Morris, Frisch, Morphew, & Constantine, 2015), working memory (Bajaj, 2007), and attentional functions (Heitmann, Asbjornsen, & Helland, 2004). Specifically, slower reaction times (Eggers, De Nil, & Van Den Bergh, 2013; Jones et al., 2012) and higher error rates in word recall accuracy and recognition (Byrd, Sheng, Bernstein Ratner, & Gkalitsiou, 2015; Moore, 1986) have been a constant finding for PWS. For example, Jones et al. (2012) found delayed reaction times and poorer accuracy of letter recall for AWS versus AWNS on concurrent tasks. These researchers proposed that the increased amounts of cognitive load on tasks requiring attention causes more vulnerable and disruptive phonological and cognitive processing in AWS. A similar effect was revealed in the present study with respect to the error rates in MWS compared to MWNS. MWS demonstrated significantly more errors for the RVF (left hemisphere processing) than MWNS. These results agree with Moore (1986), who discovered that PWS recognised and recalled less auditory word stimuli than PWNS. However, slower reaction times, as proposed by researchers investigating CWS (Eggers et al., 2013) and AWS (Maxfield et al., 2015) were not observed between MWS and MWNS in the present study. Therefore, the current results partly agree with former research suggesting less proficient performance in PWS. In the present study, it appears that lexical processing differs in MWS compared to MWNS, but only regarding an increase in error rate and not in the form of slower reaction times.

In regard to bilinguals, there is a large body of research suggesting bilinguals have an advantage in executive functioning over monolinguals (Bak, Vega-Mendoza, & Sorace, 2014; Kalashnikova & Mattock, 2014; Nicolay & Poncelet, 2013; Sullivan, Janus, Moreno, Astheimer, & Bialystok, 2014). This bilingual advantage has been found for attentional tasks that require task switching and inhibitory control (Bialystok, Poarch, Luo, & Craik, 2014; Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; Kroll & Bialystok, 2013; Morales, Calvo, & Bialystok, 2013; Soveri et al., 2011). However, some researchers have proposed a difference in the bilingual advantage between simultaneous and sequential bilinguals (Bak et al., 2014; Tao, Marzecova, Taft, Asanowicz, & Wodniecka, 2011). Both Bak et al. (2014) and Tao et al. (2011) discovered that simultaneous bilinguals mainly benefited from task switching and sequential bilinguals mainly benefited from inhibitory control. They concluded that simultaneous bilingualism particularly enhances switching processes due to expert proficiency in two languages, whereas sequential bilingualism enhances inhibitory control since it requires more inhibition of the native dominant language (Bak et al., 2014). The visual hemifield results from the current study appear to be consistent with previous research for sequential bilinguals (Bak et al., 2014; Tao et al., 2011). All of the participants were sequential bilinguals and they were required to attend only to one visual field, while ignoring the stimulus in the other visual field. The BWNS demonstrated faster reaction times than the MWNS for both the LVF and RVF. Therefore, the bilingual advantage for selective attention suggested by Bak et al. (2014) was evident for the sequential bilinguals participating in the present study. This advantage was also found for the BWS compared to the MWS. Interestingly, no significant differences were found between BWS and BWNS, either for reaction times or error rate, indicating that bilingualism might have a greater influence on executive functions than stuttering. This is further evidenced in the MWS group who demonstrated more errors for both the LVF and RVF than BWS, as well as more errors for the RVF than MWNS. Thus, MWS demonstrated the most errors compared to all other groups. It also appears that bilingualism is able to offset deficits in executive functioning that have been attributed to stuttering.

A number of researchers have suggested that bilingualism may provide cognitive reserve (Abutalebi et al., 2014; Abutalebi, Guidi, et al., 2015), which is considered to be a protective mechanism and assumed to increase the brain’s ability to cope with aging and various brain pathologies (Stern, 2009, 2012; Tucker & Stern, 2011). According to Stern (2009), reserve can be divided into brain reserve and cognitive reserve. Brain (or neural) reserve refers to individual differences in brain structure, such as more neurons or synapses that may increase resilience to brain pathology. In contrast, cognitive reserve refers to individual differences in brain function, such as better processing and task performance, that may increase tolerance to brain pathology. Brain reserve and cognitive reserve are thought to have a close interrelationship with the executive control system (Grant, Dennis, & Li, 2014). That is, superior executive functions provide the foundation for enhanced cognitive reserve, and cognitive reserve is in turn strengthened by brain reserve in terms of increased cortical integrity (white matter) and density (grey matter). Therefore, cognitive reserve may have been reflected in the visual hemifield task that required executive functions, resulting in a bilingual cognitive advantage (Tucker & Stern, 2011).

5.3 Dual-Task Paradigm

A dual-task paradigm was chosen since it was of interest to assess functional cerebral hemispheric processing associated with motor behaviour. It was assumed that dual-tasks impose higher demands on the motor system. That is, enhanced processing is required for the purpose of ensuring successful performance. The dual-task paradigm was, in contrast to the dichotic listening und visual hemifield paradigms, the only production-based test to assess hemispheric asymmetry for language. The present dual-task paradigm involved concurrent finger-tapping with either the left or right hand, while performing a verbal counting and reading task. The results revealed significant differences between the PWS and PWNS groups on some but not all of the comparisons. For all participant groups, in the majority of cases, tapping with the right hand was more interrupted than tapping with the left hand. In addition, stuttering severity was found to be correlated with the PCS-CL condition. Furthermore, all four language modalities were negatively correlated with the PCS-RL, PCS-RR, and PCS-CR conditions. That is, participants who rated themselves as highly proficient speakers of English also demonstrated fewer interruptions of finger-tapping. In contrast, no significant correlation was found between any of the language modalities and the PCS-CL condition.

5.3.1 Developmental Stuttering

***Hypothesis 1:* MWS will have significantly greater right-hemisphere dominance than MWNS on a dual-task paradigm.**

The dual-task paradigm is a behavioural measure of cerebral lateralisation of language functions. Former studies have reported relatively robust asymmetry effects in PWNS participants, evidenced by larger right-hand than left-hand tapping disruptions during concurrent manual-verbal tasks (Hellige & Longstreth, 1981; Kinsbourne & Cook, 1971). The greater tapping disruption with the right hand, paired with speaking, is assumed to suggest greater left hemisphere involvement during those tasks, with the ‘sharing’ of the left hemisphere resulting in a slower overall tapping rate. However, the results of various studies assessing dual-task performance in PWS have yielded mixed results (Brutten & Trotter, 1986; Greiner et al., 1986; Sussman, 1982). For example, Sussman (1982) found that AWS demonstrated symmetrical patterns of hemispheric language interference. That is, no differences in interference between left- and right-hand tapping were observed. The same has been found for CWS (Brutten & Trotter, 1986). These researchers found that CWS demonstrated slower tapping rates than CWNS for both the left and right hand. Considering that the CWS performed more slowly but otherwise similar to the CWNS, the researchers concluded that the neuromotor system of PWS is less robust and more vulnerable to the demands of speech production.

In the present study, it was hypothesised that MWS would have greater right-hemisphere dominance than MWNS. However, MWS performed slower than MWNS and demonstrated more interruption during the verbal counting task when tapping with the right hand. Therefore, hypothesis 1 was rejected. The MWS group also exhibited a significant difference in tapping rate between the left and right hand. No such difference was found for the MWNS group. It should be noted that verbal counting is assumed to particularly interfere with the regulation of the primary motor task as a consequence of an overlap of concurrent task demands (Andres, Seron, & Olivier, 2007). A range of functional imaging studies have indicated that number processing activates a frontoparietal cortical network that partly overlaps the one recruited for hand and finger movement control (Andres et al., 2007; Pesenti, Thioux, Seron, & De Volder, 2000; Piazza, Mechelli, Butterworth, & Price, 2002; Pinel, Piazza, Le Bihan, & Dehaene, 2004; Zago et al., 2001). Findings from Andres et al. (2007) indicated that hand motor circuits are affected every time the motor task is associated with any ordered series (e.g., counting). These researchers proposed that counting tasks could involve the premotor cortex, located within the frontal lobe of the brain, because of its role in conditioning finger movements to internal and external clues. Hence, even in the absence of actual movements, finger counting could be planned at a premotor stage. This suggestion aligns with studies by Haslinger et al. (2002) and Kuhtz-Buschbeck et al. (2003) who found involvement of the premotor cortex for imagined finger movements. This may also account for the finding of no group differences on any of the reading tasks in the present study.

Interestingly, several researchers have proposed that stuttering might be a result of a deficiency in speech-motor functions and control (Namasivayam & Van Lieshout, 2011; Peters, Hulstijn, & Van Lieshout, 2000) associated with left hemisphere motor impairment (Alm et al., 2013; Belyk, Kraft, & Brown, 2015; Neef et al., 2015). More specifically, stuttering has been linked to brain activation abnormalities in the left premotor cortex and the left motor cortex during both speech and non-speech conditions (Chang et al., 2009; Neef et al., 2015; Neef et al., 2011). For example, Neef et al. (2015) found that speech-motor plans are mainly controlled in the left motor cortex in AWNS. Yet, speech-motor planning was found in both hemispheres among AWS. They argued that this reliance on the left motor cortex appears to be a main physiological component of fluent speech production in AWNS. The different activation pattern found in AWS might be associated with a weaker structural connectivity and altered interaction between speech-related cortical regions in the left hemisphere. This assertion is supported by a large body of research claiming that stuttering is a type of disconnection syndrome due to reduced white matter in the left hemisphere speech-relevant areas (Cai et al., 2014; Chang et al., 2008; Chang, Horwitz, Ostuni, Reynolds, & Ludlow, 2011; Sommer et al., 2002; Watkins et al., 2008).

Due to the complexity of dual-task conditions, a great amount of information needs to be actively controlled and managed. Hence, dual-task performance heavily depends on executive functions (Strobach, Salminen, Karbach, & Schubert, 2014; Strobach, Soutschek, Antonenko, Floeel, & Schubert, 2015), as well as hemispheric connections (Serrien, 2009). Executive functions have been found to be mainly regulated by the prefrontal cortex (Alvarez & Emory, 2006; Moriguchi & Hiraki, 2013; Webb & Adler, 2008). In light of the fact that the prefrontal cortex is highly inter-connected with other cortical regions (Cole, Yarkoni, Repovs, Anticevic, & Braver, 2012; Rae, Hughes, Anderson, & Rowe, 2015; Yeterian, Pandya, Tomaiuolo, & Petrides, 2012), the premotor cortex may also play a role with respect to executive functions. However, executive functions have been found to be impaired in PWS (Eggers et al., 2013; Felsenfeld, Van Beijsterveldt, & Boomsma, 2010; Maxfield et al., 2015; Metten et al., 2011). Jones et al. (2012) confirmed that PWS tend to perform poorer on dual-tasks. In addition, moments of stuttering have been found to typically increase under concurrent conditions (Bosshardt, 2002; Metten et al., 2011). Several researchers have suggested that deficits in both intra-hemispheric competition and inter-hemispheric integration processes might be present in PWS (Forster & Webster, 2001; Greiner et al., 1986; Webster, 1990). This contention received support by Choo et al. (2011), who found corpus callosum differences in AWS for the region involved in inter-hemispheric processing. Specifically, the corpus callosum was found to be larger in AWS, in particular with regard to the rostrum and anterior midbody, and white matter volume was increased. The results could not be replicated with children (Choo et al., 2012). Therefore, it is likely that the neural reorganisation found for AWS may be a result of long-term adaptations to stuttering.

Based on evidence of probable impaired left hemisphere motor functions (Alm et al., 2013; Belyk et al., 2015; Neef et al., 2015), it is assumed that the two motor-based tasks (finger-tapping and speaking) used in the present study may have been taxing to the left hemisphere of the MWS participants. As a result, tapping rates were more interrupted in this particular group. This would also explain why the interruption was only found for the left but not right hemisphere. It should further be mentioned that this finding in MWS was evident regardless of the participants' stuttering severity. The correlation analysis revealed no significant relationship between stuttering severity and the PCS-CR condition. However, a positive correlation was found for the PCS-CL condition, which is consistent with findings by Szelag et al. (1993), suggesting right hemisphere involvement in severely stuttering CWS. This result might reflect a compensation mechanism of stuttering in the right hemisphere (Preibisch et al., 2003).

Some researchers have argued that verbal-manual interference tasks are a reliable and adequate tool to assess hemispheric lateralisation for language (Clark, Guitar, & Hoffman, 1985). The data of the present study seem to confirm the contention that the dual-task paradigm is not a suitable measure to determine hemispheric asymmetry for speech (Brutten & Trotter, 1985, 1986; Hughes & Sussman, 1983). Its lack of utility was made apparent by the observation that the MWNS were shown to have atypical language lateralisation in the form of hemispheric symmetry rather than asymmetry. This group did not demonstrate a greater reduction in right-hand tapping than left-hand tapping, which should have been observed since right-handed MWNS are typically left-dominant for language. In contrast, the MWS, which are generally considered to have atypical language lateralisation, were shown to have an asymmetry to the left hemisphere in the current study. Nevertheless, it was found that the performance level of the

MWS was reduced compared to MWNS, which agrees with former research (Brutten & Trotter, 1986; Sussman, 1982). The dual-task paradigm was revealing of the extent to which overall capacity is exceeded rather than indicating cerebral language lateralisation. As a result, the present findings provide support for the contention that the neuromotor system of PWS is less robust than that of PWNS.

5.3.2 Bilingualism

Hypothesis 2: ***BWNS will have significantly greater left-hemisphere dominance than MWNS on a dual-task paradigm.***

Findings of various studies assessing dual-task performance in BWNS have yielded mixed results and they are still a matter of debate. For example, several researchers have found BWNS and MWNS to perform similarly, with more right- than left-hand interference during dual-tasks (Badzakova-Trajkov et al., 2008; Hall & Lambert, 1988; Soares, 1984). In contrast, Green (1986) found proficient BWNS to have slightly greater left- than right-hand interference than less proficient BWNS, suggesting right hemisphere interference in proficient BWNS on dual-tasks. Based on findings from a meta-analysis (Hull & Vaid, 2007), in the present study, BWNS were originally expected to show more interference than MWNS for right-hand tapping as a result of greater reliance on the left hemisphere for language processes.

The present study found no differences in interference between left- and right-hand finger-tapping in BWNS, indicating equal processing resources for both hemispheres. Therefore, hypothesis 2 was rejected. Furthermore, BWNS demonstrated a faster tapping rate with the left hand compared to MWNS during the verbal reading task. This is a surprising finding given that MWNS are typically considered to show more right-hand interference (i.e., greater left hemisphere language dominance). In light of these results it appears that the current findings further support the contention that dual-task paradigms primarily reflect the extent to which overall capacity is exceeded rather than indicating language lateralisation (Brutten & Trotter, 1985, 1986; Hughes & Sussman, 1983).

The present findings can also be discussed in regard to the role of the corpus callosum in inter-hemispheric transfer of information. The theory of inhibition refers to the inhibition of connections between the two hemispheres in order to facilitate more efficient intra-hemispheric processing (Cook, 1984; Kinsbourne, 1982). The theory of excitation refers to the inter-hemispheric processing of the two hemispheres by facilitating integration of the non-stimulated hemisphere (Galaburda et al., 1990; Yazgan, Wexler, Kinsbourne, Peterson, & Leckman, 1995). That is, inhibition is associated with an increase in asymmetry, while excitation is linked to a decrease in asymmetry. Referring back to the present study, the more symmetrical presentation in the BWNS group seems to align with the excitatory theory. This is also consistent with Bloom and Hynd (2005) who suggest that the corpus callosum serves predominantly an excitatory function.

It seems reasonable to assume that the less disrupted performance of the BWNS group merely reflected better intra- and inter-hemispheric processing skills in general. This particular dual-task condition involved high processing demands, which included language processing, speech production, and manual finger-tapping. This contention is further supported by past reports that BWNS exhibit a bilingual advantage in executive functioning, especially on tasks that require monitoring and switching skills (Bialystok et al., 2014; Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; Kroll & Bialystok, 2013; Morales et al., 2013; Soveri et al., 2011; Weissberger, Gollan, Bondi, Clark, & Wierenga, 2015). These functions are considered to be crucial for successful dual-task performance.

5.3.3 Stuttering and Bilingualism

***<u>Hypothesis 3:</u>* BWS will have significantly greater left-hemisphere dominance than MWS on a dual-task paradigm.**

***<u>Hypothesis 4:</u>* BWS will have significantly greater right-hemisphere dominance than BWNS on a dual-task paradigm.**

On verbal-manual interference tasks, PWS typically show greater finger-tapping disruption for both hands compared to PWNS (Brutten & Trotter, 1986; Greiner et al., 1986; Sussman, 1982), and greater disruption for left- compared to right-hand tapping (Brutten & Trotter, 1985). Findings by researchers examining dual-tasks in BWNS have suggested greater finger-tapping disruption for the right hand (Badzakova-Trajkov et al., 2008; Furtado & Webster, 1991; Hall &

Lambert, 1988; Hoosain & Shiu, 1989; Hull & Vaid, 2006, 2007; Soares, 1984). There have been no studies examining the performance of BWS on a dual-task paradigm. Hence, the results cannot be directly compared to past research. Based on comparisons of the results obtained for the present BWS group to the MWS group, as well as to the BWNS group, it appears that the BWS and BWNS groups performed similarly on all conditions. Accordingly, hypothesis 4 was rejected. Furthermore, it was hypothesised that BWS have greater left-hemisphere dominance than MWS. However, hypothesis 3 was also rejected. Nevertheless, the MWS group demonstrated performance differences on the PCS-CR condition compared to the BWS group. Therefore, it appears that the influence of bilingualism had a greater impact on dual-task performance than the influence of stuttering.

One possible explanation of this phenomenon might be found in the brain networks associated with cognitive reserve. The concept of cognitive reserve refers to the assumption that brain networks that are more efficient and flexible are also less likely to be sensitive to interference (Stern et al., 2005). Thus, individual processing differences might result in divergent forms of reserve against brain pathology or age-related changes (Steffener, Reuben, Rakitin, & Stern, 2011; Steffener & Stern, 2012; Stern et al., 2005). According to Stern et al. (2005), there are two distinct aspects of cognitive reserve, (a) neural reserve and (b) neural compensation. Neural reserve refers to increased efficiency and/or capacity of existing functional neural resources (Steffener et al., 2011). Neural reserve is thought to reflect the normal individual capacity differences in task performance and coping mechanisms. Higher neural reserve enables brain networks not only to be more efficient but also to recruit additional resources when faced with highly demanding tasks. This is consistent with several neuroimaging studies assessing healthy participants, which reported the recruitment of additional brain areas/networks following an increase in task difficulty (Glahn et al., 2002; Grady et al., 1996; Jansma, Ramsey, Coppola, & Kahn, 2000; Rypma & D'Esposito, 1999). In contrast, neural compensation refers to the recruitment of atypical additional functional resources (Steffener et al., 2011). Neural compensation is thought to reflect an alteration of brain networks due to the physiological effects of aging or a brain pathology, resulting in a neural network that would typically not be activated by an healthy individual (Stern et al., 2005). Hence, the brain is required to compensate for the lack of resources by using altered networks whenever the level of difficulty increases in a task.

An example of a difficult, demanding task is a dual-task paradigm. In the present study, it is likely that the MWS were using neural compensation rather than neural reserve during dual-task performance.

The dual-task paradigm in the present study required time-sharing during concurrent activities (e.g., verbal and manual). The BWS group outperformed the MWS group, and performed similar to the BWNS group. This might be due to bilinguals showing enhanced executive functioning, specifically with respect to executive control (Adesope, Lavin, Thompson, & Ungerleider, 2010; Bialystok et al., 2014; Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; Kroll & Bialystok, 2013; Soveri et al., 2011). Cognitive reserve is thought to have a close interrelationship with the executive control system (Grant et al., 2014). That is, superior executive functions provide the foundation for enhanced cognitive reserve. Several researchers have reviewed the relationship of bilingualism and the brain (Bialystok, Craik, & Luk, 2012; Gold, 2015; Guzman-Velez & Tranel, 2015; Luk, Green, Abutalebi, & Grady, 2012). Interestingly, there is a growing body of research suggesting that bilingualism contributes not only to executive functioning but also to cognitive reserve. For example, it has been claimed that the levels of mental activity in which bilinguals continuously engage might even protect against some of the effects of aging and disorders (Fischer & Schweizer, 2014; Gold, Kim, Johnson, Kryscio, & Smith, 2013). More specifically, bilingualism is considered to enable a more efficient use of brain resources that assist individuals to maintain cognitive functioning in the presence of neuropathology, such as delaying the onset of Alzheimer’s disease symptoms (Craik, Bialystok, & Freedman, 2010; Gold, 2015). Therefore, neural reserve may have been reflected in the performance of the BWS and BWNS groups on the dual-task since executive functions were required, resulting in a bilingual advantage (Tucker & Stern, 2011).

It appears that BWS and BWNS were able to tolerate a greater degree of task difficulty while maintaining intact functioning presumably due to better interhemispheric processing (excitatory theory) and increased neural reserve. Hence, their brain networks were more efficient with higher capacities available. On the other hand, MWS may have required some sort of neural compensation (not required by the MWNS). It appears that they were more vulnerable to an increase of task difficulty and, therefore, demonstrated less robust functioning. In other words, cognitive reserve might have moderated the relationship between neuropathology and performance in the BWS and MWS groups. Participants with neural reserve (i.e., BWS) were able to withstand more neuropathology before cognitive function was affected, whereas the performance of participants with neural compensation (i.e., MWS) was affected sooner. The BWS group might have been able to draw on neural reserve due to their bilingualism, while the MWS were required to draw on neural compensation due to their stuttering. Thus, these findings indicate increased neural efficiency in bilinguals, a potential mechanism through which BWS may withstand at least some aspects of their neuropathology (i.e., developmental stuttering), and one that is not available to MWS.

The BWS group performed very similar to the BWNS and did not show any of the disadvantages encountered by the MWS (which were also outperformed by the MWNS), supporting the contention that developmental stuttering may be more reflective of a speech-motor than language-based communication disorder. The results generally align with research that considers stuttering to be a result of a deficiency in speech-motor control functions (Alm et al., 2013; Belyk et al., 2015; Namasivayam & Van Lieshout, 2011; Neef et al., 2015; Peters et al., 2000). The decreased performance for the MWS group, with respect to executive functions, seems to be a result of long-term compensation of motor deficits rather than a causal factor of stuttering.

6. Concluding Remarks

6.1 Clinical Implications

The present findings may have implications for clinical practice particularly with respect to the assessment and management of stuttering. The diagnosis of stuttering is typically confined to the collection of speech samples and determining the amount and types of dysfluencies (Jani, Huckvale, & Howell, 2013; Lee et al., 2014). However, executive functioning and attention control may also contribute to the management of speech fluency (Bosshardt, 2002, 2006; Metten et al., 2011; Nejati, Pouretemad, & Bahrami, 2013). Therefore, tests of executive function and attention could be considered as an adjunct to fluency assessment batteries. These tests could be used in clinical settings to elicit more complete data on the cognitive abilities of PWS not only prior to treatment but also in the course of intervention. Based on the present findings, as well as previous studies (Bosshardt, 2002; Metten et al., 2011; Nejati et al., 2013), it appears that MWS are especially limited in these particular areas in addition to their stutter. For example, Bosshardt (2002) proposed that the speech of PWS is more sensitive to interference from attention-demanding, concurrent cognitive processing within the central executive system. Metten et al. (2011) found stuttering frequency to increase on dual-tasks. It seems plausible to assume that integrating dual-task conditions into intervention programs might assist patients not only to transfer treatment effects into everyday life situations but also to maintain them. More specifically, this approach may provide extra support in situations where attentional resources are frequently diverted away from controlling fluency by the demands of other tasks. The contention receives further support by Nejati et al. (2013), who found attention training enhances executive functions and reduces stuttering severity.

6.2 Critique of Experimental Design

There were several possible confounding factors in the present study that are recognised. These factors include possible issues related to sex differences, age differences, handedness differences, stuttering severity differences, treatment effects, order effects, and the definition of bilingualism.

Sex Differences

No attempt was made to assess sex differences in performance on the three paradigms. Nevertheless, in order to avoid possible limitations due to sex differences, each of the four participant groups was carefully balanced. Each group comprised 12 men and 8 women, resulting in 48 males and 32 females in total. Former research investigating sex differences in PWS has identified either no differences (Hiscock & Mackay, 1985; Waldie & Mosley, 2000) or minor differences (Hirnstein, Westerhausen, Korsnes, & Hugdahl, 2013; Voyer, 2011) between males and females. For example, Hirnstein et al. (2013) conducted a large-scale study with behavioural and fMRI data, which indicated left hemispheric language lateralisation across all participants in both datasets. For the behavioural data, a small age-dependent difference was found for young adults but not for children or older adults. Based on past research, it seems unlikely that sex differences played an influential role in the present results.

Age Differences

Previous studies have shown that there can be age-related changes in regard to functional hemispheric asymmetry (Cherry, Adamson, Duclos, & Hellige, 2005; Dolcos, Rice, & Cabeza, 2002; Hausmann, Gunturkun, & Corballis, 2003; Petit et al., 2011; Vanhoucke, Cousin, & Baciu, 2013). For example, Dolcos et al. (2002) proposed a hemispheric asymmetry reduction in older adults compared to younger adults during cognitive performance. However, the present study controlled for possible age influences and participants were matched for age (± 5 years). Therefore, it seems unlikely that age was a limiting factor.

Handedness Differences

Participants in the present study were all right-handed. Foundas et al. (2004) found handedness differences between left- and right-handed AWS. However, most researchers claim there are no significant differences in regard to handedness (Records, Heimbuch, & Kidd, 1977; Van Der Haegen, Westerhausen, Hugdahl, & Brysbaert, 2013; Waldie & Mosley, 2000). For instance, Records et al. (1977) found no significant differences with respect to handedness, neither between PWS and PWNS nor between males and females. More recent research by Van Der Haegen et al. (2013) proposed that speech dominance is a better predictor of functional brain asymmetry than handedness. They assessed three different participant groups on a combined fMRI and behavioural study, including (1) left-hemisphere dominant left-handers, (2) right-hemisphere dominant left-handers, and (3) left-hemisphere dominant right-handers as controls. They concluded that only a small proportion of left-handers are right-hemisphere speech dominant. However, in order to avoid possible limitations due to handedness differences, all groups included only right-handed participants.

Stuttering Severity Differences

Differences in the severity of stuttering among the PWS (BWS, MWS) were not directly considered. The inclusion criteria of the PWS groups was based on an existing diagnosis of developmental stuttering by a qualified SLP. In addition, each PWS was required to judge the severity of their stuttering on a self-rating scale from 1 (mild) to 9 (severe). This procedure has been found to be a valid clinical estimate to measure stuttering severity (Karimi et al., 2014; O'Brian et al., 2004). Based on self-report, the current PWS participants' stuttering ranged from mild to severe. The mean stuttering severity was 3.5 (range = 2–7) for the BWS group and 4.1 (range = 2–9) for the MWS group with no significant difference between groups. The participants' self-rating was also consistent with the researcher's rating of their stuttering, who is also a qualified SLP. Former studies using behavioural, as well as neuroimaging, data have suggested lateralisation differences with respect to stuttering severity (Preibisch et al., 2003; Szelag et al., 1993). Similar results could be inferred in the current study for the PCS-CL condition on the dual-task paradigm. A significant positive correlation with stuttering severity was found on the counting task, suggesting greater finger-tapping disruption for the left hand, as stuttering severity increased. This is interesting in light of the results by Szelag et al. (1993), who found greater right hemisphere involvement for severe stuttering. The PWS in the present study who rated themselves to have more severe stuttering also showed greater interference on the PCS-CL condition. However, it should also be noted that the correlational analysis revealed no significant correlation between stuttering severity and any of the other behavioural paradigms and conditions. Therefore, based on the present behavioural tests and stuttering severity measures, the results indicate that hemispheric asymmetry is mainly unaffected by stuttering severity.

Treatment Effects

The effects of prior or concurrent treatment for stuttering were not assessed in the present study. However, several studies have indicated that successful speech therapy might induce a more typical activation pattern in the form of an increase in left hemisphere activity (De Nil et al., 2003; Kell et al., 2009; Neumann et al., 2003). Most of the PWS from the present study, except for two MWS, were receiving treatment for their stuttering at the time of the study or had received treatment previously. Therefore, it cannot be ruled out that treatment effects are reflected in the current findings.

Order Effects

The present study did not counterbalance the dual-task paradigm to control for order effects in comparisons of the left hand vs. the right hand. Counterbalancing refers to a process of systematically varying the order in which testing conditions are presented in order to avoid systematic bias caused by practice or boredom effects (Field, 2013). All participants were given the same sequence of stimuli, which might have influenced their responses and performance. Therefore, an order effect might have arisen since all participants started with left-hand tapping and concurrent reading, followed by right-hand tapping/reading, left-hand tapping/counting, and finished with right-hand tapping/counting. The reasons for this approach were based on the fact that there were too many participant and task variables, and possible permutations, which could not be controlled for simultaneously. Therefore, a decision was made for all participants to follow the same sequence of stimuli.

Definition of Bilingualism

The definition of bilingualism is difficult and has been recognised to be an issue in this type of research (Coalson et al., 2013). Although the majority of the world’s population is thought to be bilingual (Bhatia & Ritchie, 2006), or have at least knowledge of a second language to some degree, it is challenging to define someone who considers themself to be bilingual. However, a sufficient specification of bilingualism is necessary in research contexts to ensure replication in future research. According to Roberts (2011), bilingualism is a continuum and a number of factors should be taken into account when assessing bilinguals. These factors include a comprehensive description of participant characteristics, the use of questionnaires and self-rating scales, and maximised group homogeneity.

The present study aimed to address all of the aforementioned factors raised by Roberts (2011) in order to avoid some of the problems typically encountered in bilingualism research. It is recommended to distinguish whether exposure to both languages was simultaneously from birth or whether one language was learned sequentially after another language (Krashen, 1987; Owens, 2008). Therefore, only sequential bilinguals were included. Furthermore, all participants were required to complete a language history questionnaire, including a self-rating scale (Gollan et al., 2012; Li et al., 2006; Lim, Rickard Liow, et al., 2008), in order to obtain an estimation of their English language proficiency. The English proficiency self-rating scale ranged from 1 to 10, with a brief written description for each number, and was divided into listening, speaking, reading, and writing. This was done as per Roberts and Shenker (2007), who noted that competence varies across the expressive and receptive language modalities. Hence, it is recommended to determine a person's level of proficiency for each of the four modalities separately. Moreover, in order to increase the homogeneity of the bilingual group, only proficient participants with a self-rating of six or higher on all four language modalities were considered to be bilingual and included in the study. All people with a self-rating of four or five in any language modality were excluded to keep the monolingual and bilingual groups strictly separated.

It should be noted that even though the present study attempted to group participants according to language ability, it remains debatable whether the bilingual group was homogenous. Possible evidence of the heterogeneity of the bilingual group was found in the correlational analysis, which suggested that those bilinguals who rated themselves higher on the self-rating scale also performed better on the paradigms. Thus, there was a correlation between language proficiency and performance. Nevertheless, the criteria for defining bilingualism in the present study were rigid and based on former research. Therefore, the methodology should be replicable in future research.

6.3 Directions for Future Research

The present study raises a number of questions requiring further research in the areas of stuttering and bilingualism and their combined influence on the brain. In particular, there remains an absence of neuroimaging studies that have specifically examined the brains of BWS. Therefore, it would be important to expand the database of studies assessing functional and structural brain characteristics of BWS. The findings of the present study, using behavioural tests of hemispheric asymmetry, are a first attempt to assess brain differences in BWS compared to MWS and BWNS. However, future reseach is required to address this topic and a number of testable hypotheses could be generated. For example, it could be hypothesised that BWS demonstrate a brain structure that is more similar to BWNS (Mechelli et al., 2004; Stein et al., 2014) than to MWS (Chang et al., 2008; Civier et al., 2015; Watkins & Klein, 2011). Likewise, it would be interesting to investigate structural brain differences in BWS compared to MWS. Furthermore, the current study could be replicated using functional neuroimaging, such as fMRI, to assess hemispheric asymmetry. The detail provided by neuroimaging might be capable of detecting group differences that were not found in the present (behavioural) study.

It would be beneficial to study languages other than German to determine if the same outcome applies not only to bilinguals who are native German speakers but also to individuals with a different language background. Past research has suggested that hemispheric asymmetries may vary dependent upon languages that comprise a bilingual (Beaton et al., 2007; D'Anselmo et al., 2013; Workman et al., 2000). It might be hypothesised that languages with similar segmental and suprasegmental characteristics (e.g., German and English) also show similar language lateralisation compared to languages with more differing characteristics (e.g., German and Chinese). For example, Chinese speakers might demonstrate greater right-hemisphere dominance than German speakers due to the differences in orthography and tonal structure of the two languages. In addition, research examining differences in simultaneous, as well as sequential BWS compared to MWS might also be useful in the investigation of stuttering and bilingualism. Moreover, hemispheric asymmetries and executive functions have not yet been assessed in bilingual CWS. This might also be an area that requires further investigations. Hence it would be interesting to duplicate the present study with children.

The visual hemifield paradigm could be replicated with AWNS to test the role of visual processing time in VHF advantage. This could be tested by examining performance at 100 ms and 200 ms exposure times. It might be hypothesised that participants show greater left hemisphere involvement with extended stimuli exposure as a result of increased processing time. That is, the superior interhemispheric interaction of the right hemisphere (Doron et al., 2012; Gotts et al., 2013) may be compensated by extended presentation of the stimuli, which in turn facilitates language processing in the language-dominant left hemisphere.

An intervention study into the benefits of providing PWS not only with traditional speech therapy but also with training of executive functions might be worthwhile. This may involve the evaluation and comparison of PWS receiving treatment with and without additional executive function training, and could include measures prior to treatment and measures following speech therapy. Based on previous research, indicating that executive functioning and attention control contribute to speech fluency (Bosshardt, 2002, 2006; Metten et al., 2011; Nejati et al., 2013), it could be hypothesised that PWS receiving intervention with additional executive function training may also show sooner and better treatment outcomes. Future studies might also contribute to a better understanding of why some PWS benefit more from intervention programmes and, therefore, show better treatment outcomes than others. As a result, this may help to develop more effective therapy constructs for some PWS.

With regard to cognitive reserve, it is assumed that neural compensation occurs when normally used brain networks are altered as a result of stuttering-related neural changes (c.f. Preibisch et al., 2003). It would be interesting to further explore the notion of cognitive reserve with respect to neural reserve and neural compensation in PWS. Considering findings of (a) compensation of stuttering in the right frontal operculum (Preibisch et al., 2003), (b) greater right hemisphere involvement for severe stuttering (Szelag et al., 1993), and (c) cognitive reserve in BWNS (Abutalebi et al., 2014; Abutalebi, Guidi, et al., 2015), it seems reasonable to assume that MWS with a severe stutter draw on neural compensation (Steffener et al., 2011; Stern et al., 2005). Thus, MWS are required to recruit additional atypical resources (i.e., right hemisphere). In contrast, BWS may be able to withstand more neuropathology and draw on neural reserve due to superior executive functions. Brain reserve and cognitive reserve are thought to have a close interrelationship with the executive control system (Grant et al., 2014). That is, superior executive functions provide the foundation for enhanced cognitive reserve, and cognitive reserve is in turn strengthened by brain reserve in terms of increased cortical integrity (white matter) and density (grey matter). Thus, resulting in a bilingual advantage.

6.4 Conclusion

In conclusion, an unexpected result of the study was that all hypotheses were rejected. The tests applied to evaluate hemispheric asymmetry failed to differentiate the four participant groups according to stuttering or bilingualism. A consistent finding across all groups was wide variability in performance. This variability in performance speaks to the complexity of evaluating groups who differ in speech behaviour and language competency. As Howell and Van Borsel (2011, p. 383) noted:

> “The main lessons learned are that the only common thing about people who stutter is that they are not fluent and that the only thing bilinguals have in common is that they are not monolingual.”

While these comments seem to acknowledge the challenge of collectively studying stuttering and bilingualism, the present study is unique in its attempt to evaluate functional cerebral hemispheric processing in four diverse groups. Despite the variability observed in the current study, a prevailing finding was that bilingualism seems to be able to offset deficits in executive functioning associated with stuttering. Cognitive reserve may have been reflected in the present study, resulting in an bilingual advantage. Hence, the results of the present study lend support to previous findings implicating the benefits of bilingualism.

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Appendices

Appendix 1a: Advertisement (German)

Sprachverarbeitung bei mehrsprachigen Personen die Stottern

UNIVERSITY OF
CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Anzeige

Stottern Sie und sprechen Sie entweder Deutsch oder Deutsch und Englisch?

Ich bin an der Sprachverarbeitung bei einsprachigen und mehrsprachigen Personen die Stottern interessiert. Ich möchte herausfinden ob und wie sich Fähigkeiten in der Sprachverarbeitung von einsprachigen und zweisprachigen Personen die Stottern und nicht Stottern unterscheiden. Die Datenerhebung von dieser Studie wird sich als nützlich erweisen das Auftreten von Stottern besser zu verstehen. Hinzu kommt, dass die Ergebnisse bei der Entwicklung verbesserter Behandlungsmethoden bei Stottern behilflich sein können.

Dieses Forschungsprojekt untersucht Sprachverarbeitung mittels drei computerbasierten Tests. Die Tests beinhalten die Verarbeitung von auditiven und visuellen linguistischen Informationen, sowie verschiedene Sprechaufgaben. Die Prozedur dauert insgesamt circa zwei Stunden.

Falls Sie einwilligen teilzunehmen, werden Sie entweder in einer logopädischen Praxis oder bei Ihnen zu Hause gesehen, abhängig davon ob ein Praxisraum zur Verfügung steht. Bitte kontaktieren Sie mich wenn Sie an dieser Studie teilnehmen und mir bei meinem Forschungsprojekt helfen möchten. Sie erhalten einen Kinogutschein für Ihre Teilnahme an der Studie.

Für weitere Informationen senden Sie mir bitte eine E-Mail:

myriam.kornisch@pg.canterbury.ac.nz oder kontaktieren Sie Myriam Kornisch unter der Nummer 0173-6754826.

Appendix 1b: Advertisement (English)

Language Processing in Multilingual People who Stutter

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Advertisement

Are you a person who stutters and do you speak either German or German and English?

I am interested in the language abilities of monolingual and multilingual people who stutter. I would like to know if and how the language processing abilities differ in monolingual and bilingual people who do and do not stutter. The information gathered from this study will prove useful in further understanding the nature of stuttering. Furthermore, the information may ultimately assist in developing better treatment programmes for people who stutter.

In this research project, language abilities will be studied using three computer-based tests. The tests involve processing of auditory and visual linguistic information, as well as various speaking tasks. In total, the procedure will take approximately two hours.

If you agree to participate, you will be seen either at a speech-language pathology private practice or at your home, depending on availability of office space. Please contact me if you wish to be part of this study and help me with my research project. You will receive a cinema voucher for participating in this study.

For more information please email: myriam.kornisch@pg.canterbury.ac.nz or contact Myriam Kornisch on 0173-6754826.

Appendix 2a: Information Sheet (German)

Sprachverarbeitung bei mehrsprachigen Personen die Stottern

Information für Probanden

Sie sind eingeladen an der Studie *"Sprachverarbeitung bei mehrsprachigen Personen die Stottern"* teilzunehmen.

Bisher ist wenig bekannt über den Zusammenhang zwischen Stottern und Zweisprachigkeit. Es sind Forschungsarbeiten vorhanden die darauf hindeuten, dass sowohl einsprachige Personen die Stottern als auch zweisprachige Personen ohne Stottern im Bezug auf Sprachverarbeitung und Sprachproduktion Unterschiede aufweisen. Mit dieser Studie möchten ich anhand von vier Personengruppen untersuchen, ob Unterschiede bezüglich Sprachverarbeitung und Sprachproduktion existieren bei: (1) zweisprachigen Personen die Stottern, (2) einsprachigen Personen die Stottern, (3) zweisprachigen Personen ohne Stottern, (4) einsprachigen Personen ohne Stottern. Die Studie involviert die Durchführung von drei computerbasierten Tests, von denen jeder circa 30 Minuten zur Fertigstellung in Anspruch nehmen wird.

Falls Sie an der Studie teilnehmen möchten, werden Sie entweder in einer logopädischen Praxis oder bei Ihnen zu Hause gesehen, abhängig davon ob ein Praxisraum zur Verfügung steht. Zu Beginn der Sitzung werde ich als erstes eine kurze Anamnese mit Ihnen durchführen (circa 15 Minuten) und, falls Sie zweisprachig sind, werde ich außerdem Ihre Sprachkenntnisse in der Fremdsprache evaluieren (circa 15 Minuten). Als nächstes werde ich die drei computerbasierten Tests durchführen um die Verarbeitung von Sprache und Sprechen zu untersuchen. In einem der Tests bekommen Sie gleichzeitig zwei unterschiedliche auditive Reize präsentiert, einen ins linke Ohr und einen ins rechte Ohr, die Sie identifizieren sollen. In einem weiteren Test bekommen Sie gleichzeitig zwei unterschiedliche visuelle Reize präsentiert, einen ins linke Gesichtsfeld und einen ins rechte Gesichtsfeld, die Sie identifizieren sollen. Der dritte Test beinhaltet Sprechen in Verbindung mit Fingerklopfen, um herauszufinden wie gut Sie imstande sind beides gleichzeitig zu tun. Diese Tätigkeit wird auf Tonband aufgezeichnet werden. Die Prozedur dauert insgesamt circa 1.5 Stunden. Alle Tests werden innerhalb einer Sitzung durchgeführt, und während der Datenerhebung haben Sie die Möglichkeit von Pausen zwischen den einzelnen Tests. Ein zweiter Termin kann arrangiert werden, falls Sie außerstande sein sollten alle Tests in einer Sitzung zu absolvieren. Sie haben das Recht Ihre Teilnahme an dem Forschungsprojekt, einschließlich jeglicher bereits zur Verfügung gestellten Informationen, jederzeit zurückzuziehen.

Die Studie wird als Voraussetzung für eine Doktorarbeit in "Speech and Language Sciences" von Myriam Kornisch unter der Supervision von Professor Michael Robb durchgeführt.
Die Studie wurde von dem "Human Ethics Committee" der University of Canterbury geprüft und genehmigt (http://www.canterbury.ac.nz/humanethics/hec/index.shtml).
Falls Sie noch weitere Fragen haben sollten, stehe ich Ihnen für Rückfragen gerne zur Verfügung. Vielen herzlichen Dank.

Mit freundlichen Grüßen,
Myriam Kornisch

Myriam Kornisch, M.Sc.
Doktorandin
E-Mail: myriam.kornisch@pg.canterbury.ac.nz
Telefon: 0064 3 364 2987 ext. 3524
Handy: 0173-6754826

Professor Michael Robb
Dept. of Communication Disorders
E-Mail: michael.robb@canterbury.ac.nz
Telefon: 0064 3 364 2987 ext. 7077

Appendix 2b: Information Sheet (English)

Language Processing in Multilingual People who Stutter

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Information for Participants

You are invited to participate in the research project entitled *"Language Processing in Multilingual People who Stutter"*.

Little is known about the relationship between stuttering and bilingualism. There is research that indicates that both monolingual people who stutter and bilingual people who do not stutter may show differences in the processing and production of language. In this study I wish to examine whether differences exist in the processing and production of language in four groups of people: (1) bilinguals who stutter, (2) monolinguals who stutter, (3) bilinguals with no stutter, (4) monolinguals with no stutter. This study involves completing three computer-based tests, and each one will take approximately 30 minutes to complete.

If you are happy to join this study, you will be seen either at a speech-language pathology private practice or at your home, depending on availability of office space. At the beginning of the session, I will first conduct a brief case history (about 15 minutes) and, if you are a bilingual speaker, I will also assess your second language proficiency (about 15 minutes). Next, I will administer the three computer-based tests to assess speech and language processing. For one of the tests you will simultaneously be presented with two contrasting auditory stimuli, one to the left ear and one to the right ear, which you are required to identify. For another test, you will simultaneously be presented with two contrasting visual stimuli, one to the left visual field and one to the right visual field, which you are required to identify. The third test involves concurrently speaking while tapping your fingers to see how well you are able to do both. This task will be audio-recorded. In total, the procedure will take approximately 1.5 hours. All tests will be administered within one session, and you will be able to request breaks at any time between tests during the assessment. A second appointment can be arranged if you are unable to complete the tests in one session. You have the right to withdraw from the research project at any time, including withdrawal of any information provided.

Myriam Kornisch is carrying out this study as a requirement for a PhD in Speech and Language Sciences under the supervision of Professor Michael Robb. The research project has been reviewed and approved by the University of Canterbury Human Ethics Committee (http://www.canterbury.ac.nz/humanethics/hec/index.shtml). If you have any further questions about the study, please do not hesitate to contact me. Thank you very much.

Sincerely,
Myriam Kornisch

Myriam Kornisch, M.Sc.
PhD Student
Email: myriam.kornisch@pg.canterbury.ac.nz
Phone: 0064 3 364 2987 ext. 3524
Mobile: 0173-6754826

Professor Michael Robb
Dept. of Communication Disorders
Email: michael.robb@canterbury.ac.nz
Phone: 0064 3 364 2987 ext. 7077

Appendix 3a: Language History Questionnaire (German)

Sprachverarbeitung bei mehrsprachigen Personen die Stottern

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Fragebogen: Muttersprache und Fremdsprachen

Name

Adresse

Telefonnummer

E-Mail

Geburtsdatum

Geschlecht

Nationalität

Geburtsland

Ausbildung/höchster Bildungsabschluss

Was ist Ihre ***Muttersprache***?

Sprechen Sie mehr als eine Sprache?

Ja

Nein

Falls Sie mit ***"Nein"*** geantwortet haben, brauchen Sie dieses Formular nicht weiter ausfüllen.

1. Bitte listen Sie ***alle Sprachen die Sie sprechen*** geordnet nach Sprachkenntnissen auf (die am besten beherrschte zuerst).

SPRACHEN
1)
2)
3)
4)
5)

2. Bitte listen Sie alle ***englischsprachigen Länder*** mit Aufenthaltsdauer auf, in denen Sie mehr als drei Monate gelebt haben oder gereist sind.

LAND	**AUFENTHALTSDAUER**

3. Bitte geben Sie in der Box an, ***in welchem Alter Sie angefangen haben Englisch zu lernen*** in Bezug auf Verstehen, Sprechen, Lesen und Schreiben, sowie die Anzahl der Jahre in denen Sie ***Englisch formal gelernt*** haben.

ALTER BEI ERSTEM KONTAKT MIT ENGLISCH				**Anzahl der Jahre Englisch formal gelernt**
Verstehen	**Sprechen**	**Lesen**	**Schreiben**	

4. Bitte schätzen Sie Ihre ***englischen Sprachkenntnisse*** in Bezug auf Verstehen, Sprechen, Lesen und Schreiben gemäß der folgenden *Beschreibung* und der *Beurteilungsskala für englische Sprachkenntnisse* ein (kreisen Sie eine Nummer in der untenstehenden Tabelle ein).

Beschreibung

Verstehen: verarbeiten, verstehen, interpretieren und einschätzen von gesprochener Sprache in verschiedenen Situationen (informal und formal/professionell).

Sprechen: Beteiligung an mündlicher Kommunikation in verschiedenen Situationen, für ein breites Spektrum von Zwecken und Zuhörern (informal und formal/professionell).

Lesen: einsichtsvolles und flüssiges verarbeiten, interpretieren und einschätzen von geschriebener Sprache, Symbolen und Texten (informal und formal/professionell).

Schreiben: Beteiligung an schriftlicher Kommunikation in verschiedenen Situationen, für ein breites Spektrum von Zwecken und Zuhörern (informal und formal/professionell).

Beurteilungsskala für englische Sprachkenntnisse

1 = Anfänger niedrig (Nichtanwender): Sie haben, mit Ausnahme von ein paar einzelnen Wörtern, nicht die Fähigkeit Englisch anzuwenden.

2 = Anfänger mittel (unregelmäßiger Anwender): Sie haben große Schwierigkeiten gesprochenes und geschriebenes Englisch zu verstehen. Keine richtige Kommunikation ist möglich, bis auf grundlegendste Kommunikation in der Form von einzelnen Wörtern oder kurzen Formeln in sehr vertrauten Situationen.

3 = Anfänger hoch (sehr eingeschränkter Anwender): Sie vermitteln und verstehen nur allgemeine Bedeutungen in sehr vertrauten Situationen. In der Kommunikation treten häufige Unterbrechungen auf.

4 = Fortgeschrittener Anfänger niedrig (eingeschränkter Anwender): Ihre grundlegende Fähigkeit ist auf informale vertraute Situationen begrenzt. Sie haben häufig Probleme zu verstehen und sich auszudrücken. Sie sind nicht in der Lage komplexe Sprache zu benutzen und zu verstehen.

5 = Fortgeschrittener Anfänger mittel (einfacher Anwender): Sie haben das informale Englisch teilweise gemeistert, und in den meisten Situationen verstehen Sie den Sinngehalt. Allerdings tendieren Sie dazu noch viele Fehler zu machen. Sie sollten in der Lage sein, einfache Kommunikation in Ihrem eigenen Berufsfeld zu handhaben.

6 = Fortgeschrittener Anfänger hoch (kompetenter Anwender): Sie haben das informale Englisch, trotz einigen Ungenauigkeiten, unpassender Verwendung und Missverständnissen, weitgehend gemeistert. Sie sind einigermaßen in der Lage komplexe Sprache zu benutzen und zu verstehen, insbesondere in vertrauten Situationen.

7 = Fortgeschrittener niedrig (guter Anwender): Sie haben das informale und formale Englisch gemeistert. Allerdings kommt es in manchen Situationen noch zu Ungenauigkeiten, unpassender Verwendung und Missverständnissen. Sie kommen generell mit komplexer Sprache gut zurecht und können Argumentationen in allen Einzelheiten folgen.

8 = Fortgeschrittener mittel (sehr guter Anwender): Sie haben das informale und formale Englisch, bis auf gelegentliche unsystematische Ungenauigkeiten und unpassende Verwendung, erfolgreich gemeistert. Es mag sein, dass Sie in unvertrauten Situationen einige Dinge missverstehen. Sie sind gut in der Lage Argumentationen in allen Einzelheiten zu folgen.

9 = Fortgeschrittener hoch (Experte): Sie haben das informale und formale Englisch vollständig gemeistert. Ihre Verwendung der englischen Sprache ist angemessen, korrekt, und fließend, und Sie zeigen komplettes Sprachverstehen.

10 = Superior (muttersprachlich-ähnlicher Anwender): Ihre informalen und formalen Englischkenntnisse, einschließlich Verstehen, Sprechen, Lesen und Schreiben, sind vergleichbar mit denen eines hoch gebildeten englischen Muttersprachlers.

ENGLISCHE SPRACHKENNTNISSE			
Verstehen	**Sprechen**	**Lesen**	**Schreiben**
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
10	10	10	10

5. Falls Sie einem ***standardisierten Sprachtest in Englisch*** absolviert haben (z.B. TOEFL, IELTS), dann geben Sie bitte den Namen des Tests sowie Ihre Punktzahl an (falls Sie sich nicht an die genaue Punktzahl erinnern sollten, geben Sie eine ungefähre Schätzung an).

TEST	**GENAUE PUNKTZAHL**	**GESCHÄTZTE PUNKTZAHL**

VIELEN DANK!

Appendix 3b: Language History Questionnaire (English)

Language Processing in Multilingual People who Stutter

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Language History Questionnaire

Name

Address

Telephone Number

Email

Date of Birth

Gender

Nationality

Country of Birth

Education/Highest Qualification

What is your ***native language***?

Do you speak more than one language?

Yes

No

If you answered ***“No”***, you don’t need to continue this form.

1. Please list ***all the languages you speak*** in order of proficiency (most proficient first).

LANGUAGES
1)
2)
3)
4)
5)

2. If you have lived or travelled in ***English-speaking countries*** for more than three months, please indicate the name(s) of the country or countries, and your lengths of stay.

COUNTRY	**LENGTH OF STAY**

3. Please type in the box the ***age at which you first learned English*** in terms of listening (understanding), speaking, reading, and writing, and the number of years you have spent ***learning English formally***.

AGE OF FIRST EXPOSURE TO ENGLISH				Number of years learning English formally
Listening	Speaking	Reading	Writing	

4. Please rate your ***English Proficiency*** on listening (understanding), speaking, reading, and writing English according to the following *description* and *English language proficiency rating scale* (circle a number in the table below).

<u>Description</u>

Listening: process, understand, interpret, and evaluate spoken language in a variety of situations (informal and formal/professional).

Speaking: engage in oral communication in a variety of situations for an array of purposes and audiences (informal and formal/professional).

Reading: process, interpret, and evaluate written language, symbols and text with understanding and fluency (informal and formal/professional).

Writing: engage in written communications in a variety of forms for an array of purposes and audiences (informal and formal/professional).

<u>English Language Proficiency Rating Scale</u>

1 = Novice Low (non-user): You have no ability to use English except a few isolated words.

2 = Novice Middle (intermittent user): You have great difficulty to understand spoken and written English. No real communication is possible, except for the most basic information using isolated words or short formulae in familiar situations.

3 = Novice High (extremely limited user): You convey and understand only general meaning in very familiar situations. There are frequent breakdowns in communication.

4 = Intermediate Low (limited user): Your basic competence is limited to informal familiar situations. You frequently show problems in understanding and expression. You are not able to use and understand complex language.

5 = Intermediate Middle (modest user): You have a partial command of English, and cope with overall meaning in most informal situations, although you are likely to make many mistakes. You should be able to handle basic communication in your own field.

6 = Intermediate High (competent user): Generally you have an effective command of the informal English despite some inaccuracies, inappropriate usage, and misunderstandings. You can use and understand fairly complex language, particularly in familiar situations.

7 = Advanced Low (good user): You have an operational command of the informal and formal English, though with occasional inaccuracies, inappropriate usage, and misunderstandings in some situations. Generally you handle complex language well and understand detailed reasoning.

8 = Advanced Middle (very good user): You have a fully operational command of the informal and formal English with only occasional unsystematic inaccuracies and inappropriate usage. You may misunderstand some things in unfamiliar situations. You handle complex detailed argumentation well.

9 = Advanced High (expert user): You have a full operational command of the informal and formal English. Your use of English is appropriate, accurate and fluent, and you show complete understanding.

10 = Superior (native-like user): Your informal and formal English skills, including listening, speaking, reading and writing, are comparable to those of a highly educated English native speaker.

ENGLISH PROFICIENCY			
Listening	**Speaking**	**Reading**	**Writing**
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
10	10	10	10

5. If you have taken a ***standardized language proficiency test in English*** (e.g., TOEFL, IELTS), please indicate the name of the test and the score you received (If you don't remember the exact score, write down a guess).

TEST	ACTUAL SCORE	GUESSED SCORE

THANK YOU!

Appendix 4a: Stuttering History Questionnaire (German)

Sprachverarbeitung bei mehrsprachigen Personen die Stottern

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Fragebogen Stottern

Name

Adresse

Telefonnummer

E-Mail

Geburtsdatum

Geschlecht

Nationalität

Geburtsland

Ausbildung/höchster Bildungsabschluss

Anamnese Stottern

1. Wann haben Sie Ihr Stottern zum ersten Mal bemerkt? Gab es jemals irgendwelche neurologischen Verletzungen?

2. Wissen Sie von anderen Familienmitgliedern bei denen Stottern aufgetreten ist?

3. Waren Sie in logopädischer Behandlung?

Ja

Nein

Falls ja:

Wann?

Wo?

Wie lange?

Welcher Behandlungsansatz?

4. Gibt es Situationen in denen es Ihnen aufgrund Ihres Stotterns schwerer fällt zu sprechen?

Ja

Nein

Falls ja, können Sie Beispiele nennen?

5. Haben Sie jemals Reaktionen von anderen Menschen im Bezug auf Ihr Stottern bemerkt?

Ja

Nein

Falls ja, welche Art von Reaktionen?

6. Benutzen Sie Strategien um Ihr Stottern zu überwinden?

Ja

Nein

Falls ja, welche Art von Strategien?

7. Beurteilungsskala: Schweregrad des Stotterns

Bitte kreisen Sie die Nummer ein die dem Schweregrad Ihres Stotterns entspricht:

Deutsch: 1 2 3 4 5 6 7 8 9

Englisch: 1 2 3 4 5 6 7 8 9

1 = kein Stottern; 9 = sehr schwerwiegendes Stottern

8. Beurteilungsskala: Angstzustand bei Stottern

Bitte kreisen Sie die Nummer ein die Ihrem Angstzustand bei Stottern entspricht:

Deutsch: 1 2 3 4 5 6 7 8 9

Englisch: 1 2 3 4 5 6 7 8 9

1 = keine Angst; 9 = sehr schwerwiegende Angst

Stotterverhalten in der Fremdsprache

9. Empfinden Sie Ihr Stottern als gleich in beiden Sprachen?

Ja

Nein

Falls nicht:

a) In welcher Sprache haben Sie das Gefühl mehr zu stottern?

Deutsch

Englisch

b) Unterscheidet sich das Stottern in den beiden Sprachen?

Ja

Nein

Falls ja, in welcher Form?

10. Stört Sie das Stottern in einer Sprache mehr als in der anderen?

Ja

Nein

Falls ja, welche?

Deutsch

Englisch

Zusätzliche Informationen

11. Haben Sie auβer dem Stottern noch andere Sprech- oder Sprachstörungen?

12. Haben Sie irgendwelche schweren Krankheiten? Falls ja, welche?

Vielen Dank!

Appendix 4b: Stuttering History Questionnaire (English)

Language Processing in Multilingual People who Stutter

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Stuttering History Questionnaire

Name

Address

Telephone Number

Email

Date of Birth

Gender

Nationality

Country of Birth

Education/ Highest Qualification

Stuttering History

1. When did you first notice your stuttering? Do you know of any neurological injuries?

2. Do you know of any other cases of stuttering in your family?

3. Did you receive treatment?

Yes

No

If yes:

a) When?

b) Where?

c) How long?

d) What type of treatment?

4. Are there any situations you feel more self-conscious to talk because of your stutter?

Yes

No

If yes, can you give examples?

5. Have you ever noticed any reactions to your stuttering from other people?

Yes

No

If yes, what kind of reactions?

6. Do you use coping strategies to overcome your stuttering?

Yes

No

If yes, what kind of strategies?

7. Stutter Severity Rating Scale

Please circle the number that corresponds to your severity of stuttering:

German: 1 2 3 4 5 6 7 8 9

English: 1 2 3 4 5 6 7 8 9

1 = no stuttering; 9 = extremely severe stuttering

8. Stutter Anxiety Rating Scale

Please circle the number that corresponds to your anxiety of stuttering:

German: 1 2 3 4 5 6 7 8 9

English: 1 2 3 4 5 6 7 8 9

1 = no anxiety; 9 = extremely severe anxiety

Stuttering Behaviour in Second Language

9. Do you consider your stuttering to be the same in both languages?

Yes

No

If not:

a) Which language do you feel you stutter more?

German

English

b) Do your stuttering symptoms vary in the two languages?

Yes

No

If yes, how?

10. Does the stuttering bother you more in one language than the other?

Yes

No

If yes, which one?

German

English

Additional Information

11. Do you have any communication disorder other than stuttering?

12. Do you have any significant medical conditions? If yes, what do you have?

Thank you!

Appendix 5a: Consent Form (German)

Sprachverarbeitung bei mehrsprachigen Personen die Stottern

UNIVERSITY OF
CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Einverständniserklärung

zur Teilnahme an der wissenschaftlichen Studie

„Sprachverarbeitung bei mehrsprachigen Personen die Stottern“

Name

Adresse

Telefonnummer

Ich wurde von Myriam Kornisch über die oben genannte Studie vollständig aufgeklärt. Eine Kopie des Informationsschreiben habe ich erhalten, und ich habe die “Information für Probanden” gelesen und verstanden. Desweiteren hatte ich die Möglichkeit Fragen zu stellen, und diese wurden alle ausreichend beantwortet.

Ich hatte genügend Zeit mich zur Teilnahme an der Studie zu entscheiden und weiß dass die Teilnahme freiwillig ist. Ich wurde darüber informiert, dass ich jederzeit und ohne Angabe von Gründen diese Zustimmung widerrufen kann, alle bereits zur Verfügung gestellten Daten eingeschlossen.

Ich habe zur Kenntnis genommen, dass die Studie von der University of Canterbury geprüft und bewilligt wurde. Mir ist bekannt, dass meine Daten anonym gespeichert und aufbewahrt werden, und ausschlieβlich für wissenschaftliche Zwecke verwendet werden.

Ich erkläre hiermit meine freiwillige Teilnahme an dieser Studie, und dass ich mit der im Rahmen der Studie erfolgenden Aufzeichnung von Studiendaten und ihrer Verwendung in anonymisierter Form in Publikationen einverstanden bin.

Ort, Datum	Unterschrift des Probanden
Ort, Datum	Unterschrift der Forscherin

Appendix 5b: Consent Form (English)

Language Processing in Multilingual People who Stutter

UC
UNIVERSITY OF
CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Consent Form

to participate in the research study

“Language Processing in Multilingual People who Stutter”

Name

Address

Phone number

I have been fully informed by Myriam Kornisch about the study mentioned above. I have received a copy of the information sheet, and I have read and understood the “Information for Participants”. In addition, I was invited to discuss the project, and all my questions have been answered accordingly.

I have had sufficient time to decide whether I would like to participate in the study, and I understand that participation is voluntarily. I have been informed that I may withdraw from the study at any time, including withdrawal of any information I have provided, and that I do not have to give a reason.

I note that the project has been reviewed and approved by the University of Canterbury Human Ethics Committee. I understand that all my data will be saved and stored anonymously, and that it will exclusively be used for scientific purposes.

I agree to voluntarily participate in the study, and I consent to publication of the results of the study with the understanding that anonymity will be preserved.

Place, Date Signed (participant)

Place, Date Signed (researcher)

Appendix 6a: The Rainbow Passage (German)

Die Regenbogen Passage

Wenn das Sonnenlicht in der Luft auf Regentropfen fällt, agieren diese als ein Prisma und formen einen Regenbogen. Der Regenbogen ist eine Spaltung von weißem Licht in viele schöne Farben. Diese nehmen die Form eines langen Rundbogens an, mit seiner Bahn hoch oben und seinen zwei Enden scheinbar außerhalb des Horizonts.

Es gibt, laut einer Legende, einen Goldschatz am Ende des Regenbogens. Menschen suchen danach, aber niemand hat ihn jemals gefunden. Wenn ein Mann nach etwas außerhalb seiner Reichweite Ausschau hält, dann sagen seine Freunde, dass er auf der Suche nach dem Goldschatz am Ende des Regenbogens ist.

Über die Jahrhunderte haben Menschen den Regenbogen in unterschiedlicher Weise erklärt. Einige haben ihn als Wunder ohne fassbare Erklärung akzeptiert. Für die Hebräer war er ein Zeichen dafür, dass es keine weltumfassenden Sintfluten mehr geben würde. Die Griechen haben gedacht, dass er ein Zeichen von den Göttern ist, um Krieg oder schweren Regen vorherzusagen. Die Normannen haben den Regenbogen als eine Brücke betrachtet, über welche die Götter von der Erde zu ihrem Zuhause im Himmel passieren

Andere haben versucht das Phänomen physikalisch zu erklären. Aristotle dachte, dass der Regenbogen von Sonnenstrahlenreflexionen durch den Regen verursacht wird Seit damals haben Physiker herausgefunden, dass Regenbögen nicht durch Reflexionen sondern durch Lichtbrechung der Regentropfen verursacht werden.

Viele komplizierte Vorstellungen über den Regenbogen wurden geformt. Die unterschiedlichen Formen des Regenbogens hängen erheblich von der Größe der Regentropfen ab; die Weite des farbigen Bands wird mit der Größe der Tropfen größer. Der sichtbare Hauptregenbogen soll die Folge einer Überlagerung von mehreren Bögen sein. Wenn das Rot des zweiten Bogens auf das Grün des ersten fällt, ist das Ergebnis ein Bogen mit einem ungewöhnlichem gelben Band, da die Vermischung von rotem und grünem Licht Gelb ergibt. Ein Regenbogen, der hauptsächlich rot und gelb ist, mit nur wenig oder gar keinem grün oder blau, ist eine sehr gängige Art von Bogen.

Appendix 6b: The Rainbow Passage (English)

The Rainbow Passage

When the sunlight strikes raindrops in the air, they act as a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon.

There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

Throughout the centuries people have explained the rainbow in various ways. Some have accepted it as a miracle without physical explanation. To the Hebrews it was a token that there would be no more universal floods. The Greeks used to imagine that it was a sign from the gods to foretell war or heavy rain. The Norsemen considered the rainbow as a bridge over which the gods passed from earth to their home in the sky.

Others have tried to explain the phenomenon physically. Aristotle thought that the rainbow was caused by reflection of the sun's rays by the rain. Since then physicists have found that it is not reflection, but refraction by the raindrops which causes the rainbows.

Many complicated ideas about the rainbow have been formed. The difference in the rainbow depends considerably upon the size of the drops; the width of the colored band increases as the size of the drops increases. The actual primary rainbow observed is said to be the effect of a super-imposition of a number of bows. If the red of the second bow falls upon the green of the first, the result is to give a bow with an abnormally wide yellow band, since red and green light when mixed form yellow. This is a very common type of bow, one showing mainly red and yellow, with little or no green or blue.

Appendix 7: Participant Characteristics

Table 9. *Characteristics of the BWS Group.*

Participant	Sex	Age (in Years)	LHQ Listening	LHQ Speaking	LHQ Reading	LHQ Writing	Stuttering Severity	Stuttering Anxiety	Family History	Speech Therapy
1	Male	27	8	7	9	8	2	1	No	Yes
2	Male	31	8	7	9	7	6	1	Yes	Yes
3	Male	22	7	6	8	6	3	2	No	Yes
4	Female	51	9	9	9	9	5	3	N/A	Yes
5	Male	28	8	7	9	9	2	2	Yes	Yes
6	Male	36	6	6	6	6	2	1	No	Yes
7	Male	34	8	8	8	8	2	1	Yes	Yes
8	Male	54	6	6	6	6	5	3	Yes	Yes
9	Female	21	8	8	8	7	2	3	No	Yes
10	Female	36	7	6	7	6	6	7	No	Yes
11	Male	31	6	6	6	6	3	4	No	Yes
12	Male	57	6	6	6	6	2	2	Yes	Yes
13	Female	28	8	7	9	7	3	2	No	Yes
14	Male	21	7	6	8	6	3	2	Yes	Yes
15	Female	39	7	6	8	7	4	6	Yes	Yes
16	Female	29	6	6	6	6	4	6	Yes	Yes
17	Female	46	7	6	7	6	4	4	Yes	Yes
18	Male	34	7	6	7	6	3	3	Yes	Yes
19	Female	49	7	6	8	6	7	2	Yes	Yes
20	Male	52	7	7	7	7	2	4	No	Yes
Mean		36	7.15	6.60	7.55	6.75	3.50	2.95		
SD		11	.88	.88	1.15	1.02	1.57	1.76		

Note. ***LHQ:*** Language History Questionnaire for Listening, Speaking, Reading, and Writing (Scale 1-10) for the English Language; ***Stuttering Severity:*** Rating Scale 1-9 (German Language); ***Stuttering Anxiety:*** Rating Scale1-9 (German Language); ***Family History:*** Stuttering

Table 10. *Characteristics of the BWNS Group.*

Participant	Sex	Age (in Years)	LHQ Listening	LHQ Speaking	LHQ Reading	LHQ Writing
1	Male	29	7	6	6	6
2	Male	29	8	7	8	8
3	Male	25	7	6	7	6
4	Female	55	7	6	7	6
5	Male	27	7	7	7	6
6	Male	38	6	6	6	7
7	Male	31	9	9	9	9
8	Male	52	6	6	6	6
9	Female	18	7	6	7	6
10	Female	32	9	8	9	8
11	Male	28	7	7	9	8
12	Male	58	7	6	7	6
13	Female	29	8	6	8	6
14	Male	23	7	6	7	7
15	Female	39	6	6	7	6
16	Female	30	10	9	10	9
17	Female	47	8	8	8	8
18	Male	33	7	7	8	8
19	Female	51	8	7	8	7
20	Male	49	7	6	7	6
Mean		36	7.40	6.75	7.55	6.95
SD		12	1.05	1.02	1.10	1.10

Note. ***LHQ:*** Language History Questionnaire for Listening, Speaking, Reading, and Writing (Scale 1-10) for the English Language

Table 11. *Characteristics of the MWS Group.*

Participant	Sex	Age (in Years)	LHQ Listening	LHQ Speaking	LHQ Reading	LHQ Writing	Stuttering Severity	Stuttering Anxiety	Family History	Speech Therapy
1	Female	41	1	1	1	1	4	9	No	Yes
2	Male	40	1	1	1	1	3	1	No	Yes
3	Female	37	3	3	3	3	4	2	Yes	Yes
4	Male	55	1	1	1	1	5	5	No	Yes
5	Male	46	1	1	1	1	4	3	Yes	No
6	Male	46	3	3	3	3	2	3	Yes	Yes
7	Female	49	3	3	3	3	5	3	Yes	Yes
8	Female	30	3	2	3	2	7	9	No	Yes
9	Male	49	3	3	3	3	6	2	No	No
10	Male	37	3	3	3	3	2	2	No	Yes
11	Male	47	3	2	3	2	5	4	Yes	Yes
12	Male	28	3	3	3	3	3	3	No	Yes
13	Male	53	3	3	3	3	2	1	No	Yes
14	Male	48	3	3	3	3	3	3	Yes	Yes
15	Female	55	1	1	1	1	9	9	No	Yes
16	Female	32	3	3	3	3	4	1	Yes	Yes
17	Female	25	3	3	3	3	5	6	No	Yes
18	Male	49	1	1	1	1	2	1	No	Yes
19	Male	20	3	3	3	3	4	2	Yes	Yes
20	Female	41	1	1	1	1	3	3	No	Yes
Mean		41	2.30	2.20	2.30	2.20	4.10	3.60		
SD		10	.98	.95	.98	.95	1.80	2.66		

Note. ***LHQ:*** Language History Questionnaire for Listening, Speaking, Reading, and Writing (Scale 1-10) for the English Language; ***Stuttering Severity:*** Rating Scale 1-9 (German Language); ***Stuttering Anxiety:*** Rating Scale1-9 (German Language); ***Family History:*** Stuttering

Table 12. *Characteristics of the MWNS Group.*

Participant	Sex	Age (in Years)	LHQ Listening	LHQ Speaking	LHQ Reading	LHQ Writing
1	Female	42	1	1	1	1
2	Male	41	1	1	1	1
3	Female	35	1	1	1	1
4	Male	58	1	1	1	1
5	Male	52	1	1	1	1
6	Male	42	1	1	1	1
7	Female	50	1	1	1	1
8	Female	33	3	3	3	3
9	Male	51	1	1	1	1
10	Male	35	2	2	2	2
11	Male	47	1	1	1	1
12	Male	23	1	1	1	1
13	Male	56	1	1	1	1
14	Male	44	1	1	1	1
15	Female	52	3	3	3	3
16	Female	34	3	3	3	3
17	Female	26	3	3	3	3
18	Male	45	1	1	1	1
19	Male	24	3	2	3	2
20	Female	45	1	1	1	1
Mean		42	1.65	1.60	1.65	1.60
SD		10	.93	.88	.93	.88

Note. ***LHQ:*** Language History Questionnaire for Listening, Speaking, Reading, and Writing (Scale 1-10) for the English Language

Appendix 8: Individual Dichotic Listening Results

Table 13. *Individual Dichotic Listening Results for all Participant Groups.*

Participant	**BWS**		**BWNS**		**MWS**		**MWNS**	
	L=R (%)	**IID (dB)**	**L=R (%)**	**IID (dB)**	**L=R (%)**	**IID (dB)**	**L=R (%)**	**IID (dB)**
1	75	49	25	16	8	-6	16	5
2	-16	-25	25	31	-8	33	33	260
3	50	-140	41	26	33	61	83	93
4	16	25	8	-4	-16	11	-33	-56
5	16	37	91	120	25	56	0	-37
6	-25	15	0	-14	25	48	33	30
7	0	-20	58	-99	58	57	-25	-3
8	41	-15	0	-46	16	17	0	-7
9	33	1	8	28	-8	52	25	72
10	0	30	-25	-25	33	-25	0	16
11	8	45	0	4	8	-12	33	37
12	0	-280	-8	0	16	19	0	22
13	66	-220	-16	-46	8	-8	91	390
14	25	-190	16	32	50	71	41	6
15	66	40	25	15	-8	-2	0	-14
16	0	13	8	13	-8	0	75	48
17	25	16	-8	-24	8	26	25	36
18	25	14	58	-55	0	-42	-25	-2
19	25	-1100	16	12	0	32	25	-34
20	25	170	0	140	16	1	8	-15
Mean	22	-76	16	6	12	19	20	42
SD	27	263	28	54	20	31	34	105
Median	25	13	8	8	8	18	20	11

Note. ***L=R:*** Equal Binaural Intensity, IID = 0 dB (%); ***IID:*** Interaural Intensity Difference; “cross-over point” (dB)

Appendix 9: Individual Visual Hemifield Results

Table 14. *Individual Visual Hemifield Results for the BWS Group.*

Participant	Reaction Time				Errors			
	LVF (ms)	**RVF (ms)**	**VHFA (ms)**	**ND (%)**	**LVF**	**RVF**	**VHFA**	**ND (%)**
1	1896	1894	2	0	1	0	1	200
2	1263	1344	-81	-6	2	0	2	200
3	1610	1732	-122	-7	1	4	-3	-120
4	1892	1856	36	1	12	8	4	40
5	1796	1931	-135	-7	2	0	2	200
6	1533	1623	-90	-5	4	2	2	66
7	1885	1834	51	2	11	5	6	75
8	2422	2880	-458	-17	1	3	-2	-100
9	1478	1698	-220	-13	3	6	-3	-66
10	1544	1520	24	1	1	1	0	0
11	1756	1772	-16	0	3	2	1	40
12	N/A	N/A	N/A	N/A	2	80	-78	-190
13	1359	1503	-144	-10	3	5	-2	-50
14	1611	1588	23	1	0	0	0	0
15	1814	1953	-139	-7	2	2	0	0
16	1674	1763	-89	-5	2	1	1	66
17	1617	1948	-331	-18	10	4	6	85
18	1900	1920	-20	-1	1	4	-3	-120
19	1844	2165	-321	-16	22	9	13	83
20	2050	2217	-167	-7	1	9	-8	-160
Mean	1733	1849	-115	-6	4	7	-3	12
SD	263	332	138	6	5	17	18	116
Median	1756	1834	-90	-6	2	3	0	20

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

Table 15. *Individual Visual Hemifield Results for the BWNS Group.*

Participant	Reaction Time				Errors			
	LVF (ms)	**RVF (ms)**	**VHFA (ms)**	**ND (%)**	**LVF**	**RVF**	**VHFA**	**ND (%)**
1	1342	1348	-6	0	2	1	1	66
2	1707	2180	-473	-24	1	9	-8	-160
3	1474	1571	-97	-6	1	3	-2	-100
4	1607	1658	-51	-3	18	21	-3	-15
5	1437	1570	-133	-8	5	0	5	200
6	1354	1581	-227	-15	0	4	-4	-200
7	1780	1797	-17	0	2	4	-2	-66
8	1900	2092	-192	-9	2	3	-1	-40
9	1393	1606	-213	-14	1	5	-4	-133
10	1595	1706	-111	-6	10	12	-2	-18
11	1505	1627	-122	-7	1	1	0	0
12	1872	1860	12	0	3	1	2	100
13	2046	1978	68	3	4	1	3	120
14	1497	1507	-10	0	6	3	3	66
15	1431	1491	-60	-4	1	6	-5	-142
16	1542	1371	171	11	1	0	1	200
17	2053	1878	175	8	4	4	0	0
18	1261	1438	-177	-13	1	4	-3	-120
19	1661	1847	-186	-10	9	10	-1	-10
20	2634	2168	466	19	3	1	2	100
Mean	1654	1713	-59	-4	3	4	0	-7
SD	324	252	191	10	4	5	3	116
Median	1568	1642	-78	-5	2	3	-1	-12

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

Table 16. *Individual Visual Hemifield Results for the MWS Group.*

Participant	Reaction Time				Errors			
	LVF (ms)	RVF (ms)	VHFA (ms)	ND (%)	LVF	RVF	VHFA	ND (%)
1	2136	2524	-388	-16	28	34	-6	-19
2	1932	2078	-146	-7	5	8	-3	-46
3	2008	1971	37	1	10	5	5	66
4	3117	3236	-119	-3	17	8	9	72
5	2627	2566	61	2	9	21	-12	-80
6	3584	3644	-60	-1	11	15	-4	-30
7	1882	2004	-122	-6	5	6	-1	-18
8	1561	1490	71	4	0	2	-2	-200
9	1787	2136	-349	-17	30	41	-11	-30
10	2172	2572	-400	-16	7	11	-4	-44
11	3172	3133	39	1	52	44	8	16
12	2471	2561	-90	-3	1	2	-1	-66
13	1823	2008	-185	-9	16	9	7	56
14	1975	1907	68	3	1	5	-4	-133
15	1954	1954	0	0	14	16	-2	-13
16	1797	1798	-1	0	19	21	-2	-10
17	1577	1574	3	0	1	2	-1	-66
18	2062	2071	-9	0	0	7	-7	-200
19	1566	1596	-30	-1	24	39	-15	-47
20	2004	2132	-128	-6	10	8	2	22
Mean	2160	2247	-87	-3	13	15	-2	-38
SD	561	572	146	6	12	13	6	74
Median	1989	2074	-45	-1	10	8	-2	-30

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

Table 17. *Individual Visual Hemifield Results for the MWNS Group.*

Participant	Reaction Time				Errors			
	LVF (ms)	RVF (ms)	VHFA (ms)	ND (%)	LVF	RVF	VHFA	ND (%)
1	2038	2420	-382	-17	23	13	10	55
2	1934	2336	-402	-18	1	2	-1	-66
3	1937	2121	-184	-9	28	19	9	38
4	2204	2217	-13	0	9	13	-4	-36
5	1714	1713	1	0	5	5	0	0
6	1667	1741	-74	-4	0	3	-3	-200
7	2750	2677	73	2	11	7	4	44
8	1760	1834	-74	-4	1	2	-1	-66
9	1688	1898	-210	-11	2	3	-1	-40
10	1751	1767	-16	0	1	3	-2	-100
11	1923	1833	90	4	0	3	-3	-200
12	1618	1787	-169	-9	13	3	10	125
13	2253	2353	-100	-4	2	1	1	66
14	1642	1592	50	3	0	1	-1	-200
15	2118	2065	53	2	9	8	1	11
16	1631	1624	7	0	6	2	4	100
17	1461	1404	57	3	0	1	-1	-200
18	1752	1740	12	0	5	10	-5	-66
19	1913	1990	-77	-3	2	5	-3	-85
20	1522	1647	-125	-7	8	17	-9	-72
Mean	1863	1937	-74	-3	6	6	0	-44
SD	302	326	139	6	7	5	4	101
Median	1756	1833	-45	-2	3	3	-1	-53

Note. ***LVF:*** Left Visual Field; ***RVF:*** Right Visual Field; ***VHFA:*** Visual Hemifield Advantage; ***ND:*** Normalised Difference

Appendix 10: Individual Dual-Task Results

Table 18. *Individual Dual-Task Results for the BWS and BWNS Groups.*

Participant	BWS				BWNS			
	PCS-RL (%)	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**	**PCS-RL (%)**	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**
1	-3	0	-4	2	-1	5	-2	7
2	-18	-14	28	-12	4	10	15	22
3	14	16	7	4	0	2	3	1
4	-22	19	-1	23	11	10	11	37
5	13	-11	8	-8	5	2	10	-1
6	13	20	-5	0	-25	23	20	41
7	15	19	13	20	-26	8	-15	29
8	59	19	31	67	42	-14	53	25
9	11	2	28	13	6	15	5	10
10	23	7	7	0	5	5	5	0
11	4	15	8	8	4	7	-2	5
12	21	21	24	12	21	8	1	26
13	1	0	-2	-3	2	5	6	3
14	4	15	5	9	0	7	3	15
15	5	0	12	-11	3	4	2	2
16	10	14	33	7	-3	-6	-11	-20
17	0	35	81	28	3	1	12	0
18	23	5	3	-2	8	9	4	2
19	10	4	9	7	4	12	2	13
20	5	13	11	7	6	4	33	29
Mean	9	10	15	8	3	6	8	12
SD	16	12	19	17	14	7	15	15
Median	10	14	9	7	4	6	5	8

Note. ***PCS-RL:*** Percent Change Score – Reading/Finger-Tapping with Left Hand; ***PCS-RR:*** Percent Change Score – Reading/Finger-Tapping with Right Hand; ***PCS-CL:*** Percent Change Score – Counting/Finger-Tapping with Left Hand; ***PCS-CR:*** Percent Change Score – Counting/Finger-Tapping with Right Hand

Table 19. *Individual Dual-Task Results for the MWS and MWNS Groups.*

Participant	MWS				MWNS			
	PCS-RL (%)	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**	**PCS-RL (%)**	**PCS-RR (%)**	**PCS-CL (%)**	**PCS-CR (%)**
1	-20	6	56	62	1	11	4	20
2	34	78	22	88	33	22	39	22
3	47	26	51	32	42	9	61	35
4	28	-15	65	77	61	88	5	80
5	10	22	15	24	33	67	48	8
6	9	11	4	7	6	0	5	-1
7	36	5	50	2	7	13	-41	12
8	0	59	0	6	89	16	26	2
9	8	17	-12	4	90	91	91	47
10	-102	21	-118	51	-14	-54	30	-22
11	81	80	45	63	40	18	3	-4
12	8	22	8	21	-6	0	5	6
13	18	14	15	50	10	54	11	60
14	22	16	7	-1	17	3	4	-4
15	73	18	71	82	10	11	2	-3
16	3	6	6	20	7	-11	14	-9
17	11	15	18	9	6	2	-2	-1
18	4	18	6	7	-39	-1	-34	30
19	20	0	25	32	5	15	-11	-8
20	-35	10	-48	27	8	5	20	5
Mean	13	21	14	33	20	18	14	13
SD	38	24	42	28	32	34	30	25
Median	11	17	15	25	9	11	5	5

Note. ***PCS-RL:*** Percent Change Score – Reading/Finger-Tapping with Left Hand; ***PCS-RR:*** Percent Change Score – Reading/Finger-Tapping with Right Hand; ***PCS-CL:*** Percent Change Score – Counting/Finger-Tapping with Left Hand; ***PCS-CR:*** Percent Change Score – Counting/Finger-Tapping with Right Hand