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An Investigation Of Motor Speech And Motor Limb Movements Following A Sport-Related Concussion-An Extension Study

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AN INVESTIGATION OF MOTOR SPEECH AND MOTOR LIMB MOVEMENTS

FOLLOWING A SPORT-RELATED CONCUSSION-AN EXTENSION STUDY

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Dedication

This is for you, Mom.

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by

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THESIS

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Abstract

Background: Minimal research is available regarding the effects on motor speech and motor limb movements following a sport-related concussion (SRC). A sensitive measure is necessary to detect subtle deficits in motor speech, as it may provide diagnostic insight involving return-to-play decisions.

Purpose: This research aimed at replicating and extending a previous research study, Hewitt (2015), conducted at the University of Texas at El Paso. The Hewitt (2015) study examined motor speech tasks and motor limb tasks which included the following: oral diadochokinetics (DDK): sequential motion rate (SMR)(i.e. /puh-tuh-kuh/) and alternating motion rate (AMR) (i.e. /puhpuhpuh/, /tuhtuhtuh/, /kuhkuhkuh/); speech rate tasks; intelligibility in a sentence repetition task; and motor limb tasks: movement execution initiation and finger repetition, in athletes following a SRC.

Methods: Given the sample of 22 SRC participants, the database of baseline measures (control group) was searched to match these 22 individuals and was closely matched by age and gender. Motor speech and motor limb tasks were examined in the 22 individuals (12 males, 10 females; age = 18.50 years ± 2.36) post-SRC and 22 individuals (11 males, 11 females; age = 17.91 years ± 3.14) in the control group. Participants from both the SRC group and the control group include retrospective data from Dolan (2013) and Hewitt (2015) to create a larger number of participants in both groups. DDK tasks: SMR and AMR were measured and acoustically analyzed using Kay Elemetrics: CSL, model 4500. Speech rates were determined using the computerized Sentence Intelligibility Test software. Motor limb tasks included a finger repetition task and a movement execution initiation time task. Total duration times for all speech and the motor limb tasks were compared between groups.

Results: There was an overall slower DDK mean syllable duration time and total duration time in the SRC compared to the control group. Additionally, motor limb tasks demonstrated slower duration times for the finger repetition task and movement execution initiation time task in the SRC compared to the control group. Furthermore, analysis of speech rate tasks did not reveal the SRC group to have slower speech rate compared to the control group. In addition, no statistical significance was found in the speech rate task between the groups. Lastly, these results were compared to the Hewitt (2015) study.

Conclusion: This study provides evidence that motor speech and motor limb impairments are found in athletes with SRC. Motor speech tasks may provide valuable information regarding implications of the speech mechanism post- SRC and may further facilitate clinical decision-making in concussion management.

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Chapter 1: Introduction

Given the increasing frequency of sport-related concussion, the consequences of brain injury are of great concern and continue to grow. Though there have been significant strides in the management and care of concussed athletes, confusion among coaches, athletic trainers, and players still remain confused regarding the awareness of concussion, the extent of its effects on the brain, and proper management (May, Marshall, Burns, Popoli, & Polikandriotis, 2014). Premature decisions to release athletes to return to the playing field may result in delayed recovery, prolonged symptoms, or even more serious consequences such as diffuse cerebral swelling or second-impact syndrome (SIS) (Gronwall & Wrightson, 1975; Guskiewicz et al., 2003; Collins et al., 2002).

The CDC estimate 1.6 to 3.8 million recreational and sports-related concussions occur each year in the United States. The traditional incidence rate for concussion is estimated at 300,000 cases in a given year (Broglio & Guskiewicz, 2009). Researchers suggest that as the number of diagnosed sport-related concussion increases, the concern for its effects and possible long-term effects have become an important public health problem (Laker, 2011; Clay, Glover, Lowe, 2012). A concussion is a bump, blow, or jolt to the head that is typically characterized by natural recovery and resolution of clinical signs and symptoms within a fairly short period of time (Salvatore & Sirmon Fjordbak, 2011). The recovery period for a concussion is typically around 10-14 days (Collins, 2002; Iverson et al., 2003; Iverson et al., 2006; McCrea, 2008; Edward & Bodle, 2014). Studying the effects of concussion and the course of recovery is a critical step toward determining the decision for an individual to return-to-play (RTP), as well as their return to the classroom setting. Available data indicates that a safe RTP guideline is crucial

and should include about 4 to 6 weeks to facilitate a complete recovery from the initial impact to prevent and protect from a second injury (McKee, Cantu, & Nowinski, et al. 2009).

Due to the increase in incidence for concussion, is it necessary to have the appropriate assessment tools to properly examine the deficits that follow a concussion. The motor system, which includes the speech motor system, is comprised of complex network structures that organize, control, and execute movement (Duffy, 2013). It is reasonable to hypothesize that because motor speech movements are under the same control circuit for motor limb movements, that both functions would be involved after sustaining a concussion, as a result of neural damage. In past research, the following assessment tools have been used to detect impairments for speech intelligibility and motor limb movements: oral diadochokinetics, a Sentence Intelligibility Test, and motor limb tasks. Appropriate assessment tasks are necessary to identify any motor speech deficits following a sports-related concussion, as this will help the clinician gain better insight on the level of impairment. In addition, it will enable the clinician to confidently address return-to-play and academic decisions, which may help student athletes from returning to play and school before a full recovery.

This study seeks to systematically replicate and extend previous research in examining the effects of motor speech and motor limb movements in individuals with and without a sport-related concussion. This study extends the Dolan (2013) study and the Hewitt (2015) study by increasing the sample size for both the control group and the experimental group. Furthermore, the current study will extend previous research by examining the relationship between ImPACT composite scores (i.e., verbal memory, visual memory, and reaction time) and oral diadochokinetics, Sentence Intelligibility Test, and motor limb tasks, which were not accomplished in the two earlier investigations.

1.1 Definition and epidemiology

The definition of concussion and the criteria guidelines for its diagnosis are varied between different organizations and professional fields of study (Laker, 2011). The Fourth International Conference on Concussion in Sport defines concussion as a "complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (McCrory et al., 2013). Harmon et al (2013) agree that concussion is a "traumatically induced disturbance of brain function that involves a complex physiological process". In addition, Harmon et al (2013) further define concussion as a subset of mild traumatic brain injury (mTBI). Some studies define mTBI by using a Glasgow Coma Scale score of ≥13, whereas other authors use International Classification of Diseases, Revision 9 (ICD-9) codes that would correspond to mTBI (Lovell et al., 2006; Cantu, 2001). The variability that surrounds the injury makes it difficult for researchers to form a consensus for a definitive definition. However, all definitions share common characteristics in the underlying pathophysiological process of concussion (Edwards & Bodle, 2014). Researchers agree that a concussion is an acquired brain injury that is accompanied by specific neurobehavioral symptoms (Raskin & Mateer, 2000). Evidence-based sport guidelines were developed by international consensus defining concussion as a complex pathophysiological process affecting the brain, induced by traumatic biochemical forces (Clay, Glover, & Lowe, 2013). There are several constructs that can be utilized to define the nature of a concussive brain injury that incorporate clinical, pathological, and biomechanical features. Concussion may be caused by a direct blow to the head, face, or neck with an "impulsive" force transmitted to the head. In addition to this, concussion typically results in rapid onset of short-lived neurologic function impairments caused by neuropathologic changes that reflect a functional disturbance rather than a structural injury (McCrory, Meeuwisse, Johnston, Dvorak,

Aubry, Molly, & Cantu, 2009). Loss of consciousness is not a required criterion for a diagnosis of a concussion. Symptoms that typically manifest include dizziness, headaches, and visual disturbances. Giza and Hovda (2001) suggest that because these post-concussive deficits are transient and minimally detectable anatomically, they are based on temporary neuronal dysfunction rather than on cellular death.

Despite the variability in the definition, there are large reviews and estimates for its occurrence have been undertaken (Laker, 2011). Research provides evidence that the causes of sport-related concussions are multifaceted, but majority of injuries occur from player to player contact, with certain contact sports creating higher rates of concussion than others (Laker, 2011). For example, Laker (2011) notes that boys football and girls soccer are the highest contributors to the percentage of sport-related concussion. Additionally, it is reported that females have nearly twice the rate of concussion in comparable male sports (Laker, 2011). However, gender and age difference is a continued area of research and warrants further clarification in terms of individualized treatment (Laker, 2011).

1.2 Metabolic effect

A concussion sets in motion a neurological dysfunction caused by a biomechanical force, which then causes a neuronal disruption that can last for 6-24 hours post-injury (Giza & Hovda, 2001). Damage to the physical structure of the brain results in a series of pathophysiological events that begin with an abrupt neuronal depolarization, which leads to a release of excitatory neurotransmitters (McCrea, 2008). The sudden release of excitatory neurotransmitters causes an efflux of potassium (K^+) and an influx of calcium (Ca^+) that lead to ionic shifts and changes in glucose metabolism (McCrea, 2008). The sodium-potassium (Na^+-K^+) pump works overtime, as it requires increased amounts of adenosine triphosphate (ATP), which then triggers a jump in

glucose metabolism, called hypermetobolism (Giza & Hovda, 2001; McCrea, 2008). During this state of diminished cerebral blood flow caused by hypermetobolism, the disparity between glucose supply and demand triggers a cellular energy crisis (Giza & Hovda, 2001). This is suspected to be the mechanism for post-concussive vulnerability, rendering the brain less able to respond adequately to a second injury and leading to more persistent deficits (McCrea, 2008). Giza and Hovda report that long-term deficits in memory and cognition, post-concussion, may be attributed to dysfunctional excitatory neurotransmissions. Evidence suggests that the symptoms that manifest are due to this pathophysiological process typically resolved by ten days (Iverson, Lovell, & Collins, 2006). However, Henry and colleagues (2015) postulate that recovery outcomes are actually 21-28 days, suggesting a longer time frame than the purported time frame of 7-14 days.

1.3 Post- concussion syndrome (PCS)

Concussion symptoms have been documented to typically resolve within 7-14 days post-injury (Edwards & Bodle, 2014). However, there are some individuals that experience persistent symptoms, known as post-concussion syndrome. Though there is yet a universal definition for postconcussion syndrome, most literature defines the syndrome as having at least three of the following symptoms: headache, dizziness, fatigue, irritability, impaired memory and concentration, insomnia, and lowered tolerance for noise and light, lasting more than 3 months to several years and may even cause disability (Ryan & Warden, 2003; Cancelliere, et al., 2014; Legome, Wu, & Mills, 2015).

1.4 Cumulative effects and chronic traumatic encephalopathy (CTE)

Most sport-related head injuries recover within a few days or weeks post-injury but there are a small percentage of individuals that develop long-lasting symptoms (McKee, Cantu, &

Nowinski, et al. 2009). The pathophysiological effects of a concussion fall on a continuum and it is believed that due to the increased force caused by acceleration/deceleration, the number of damaged cells increases as damage progressively occurs in deeper structures, which then results in an increased vulnerability and/or lowered threshold for subsequent concussions after the initial concussion (Gaetz, Goodman, and Weinberg, 2000; Collins et al., 2002; Guskiewicz et al., 2003, McCrea, 2008). Therefore, as the number of diagnosed sport-related concussion grows, there is an increased focus on the neurological sequelae that occurs as a result of repeated concussion, causing long-term neurological deterioration, known as Chronic Traumatic Encephalopathy (CTE) (Guskiewicz et al., 2003). CTE is clinically associated with memory disturbances and personality changes, and pathologically shares the same features of Alzheimer's Disease and Parkinson's Disease (McKee et al., 2009). Post- mortem autopsy, performed on former athletes, revealed out of 51 neuropathologically confirmed cases, 46 cases were confirmed with CTE (McKee et al., 2009).

1.5 Second impact syndrome (SIS)

Another consequence of repeated brain injury is Second Impact Syndrome (SIS). Though rare, this occurs when an athlete returns to play and sustains another concussion before the previous concussion has resolved. The consequences of cerebral swelling, brain herniation, and death can occur if careful and conservative RTP decisions are not made to prevent a premature return to the game (Bey & Ostick, 2009). Researchers suggest that SIS may be linked to the athlete not reporting the concussive symptoms (knowingly or unknowingly), or that proper assessment procedures are not being implemented by the coach, athletic trainer, or other health care professionals (Mcrea et al., 2004).

Chapter II: Literature Review

Concussive injuries can vary across athletes, resulting in variable deficits across concussed individuals (McCrory et al., 2014). Drummond and Boss (2004) note that two patterns of communication deficits may be a consequence of moderate to severe TBI. One pattern is damage due to diffuse injury that causes deficits in cognitive function such as attention, memory, and information processing. A second pattern is damage due to focal injury that causes specific speech and language deficits, similar to dysarthria or stroke (Drummond & Boss, 2004).

Dysarthria is a motor speech disorder that is a result of impaired control of speech musculature, which creates difficulties with motor speech production, including respiration, phonation, resonance, articulation, and prosody (Chapey, 2008). Apraxia of Speech (AOS) is also a motor speech disorder. However, it does not commonly occur in closed head injuries (Cannito, 2014). AOS will not be discussed further for this study. Though dysarthria does not commonly occur in cases of sport-related concussion, it has been noted to occur in many cases of TBI, in individuals with repeated head injuries, and/or cases of moderate to severe concussion (Goozee, Murdoch, and Theodoros, 2000; Murdoch, Theodoros, and Goozee, 2001; Nishio & Niimi, 2001; Bartle, Goozee, Scott, Murdoch, & Kuruvilla, 2006; Morgan, Liegeois, & Occomore, 2007; McAuliffe, Carpenter, & Moran, 2010; Murdoch, Kuruvilla, Goozee, 2012; Cannito, 2014). Few studies have provided evidence of SRC related dysarthria in one or more individuals (Murdoch, Kuruvilla, and Goozee, 2012; Murdoch, Theodoros, and Goozee, 2001).

2.1 Effects of dysarthria post-TBI

Motor speech disorders exhibit specific deviant speech characteristics based on the location and extent of the damage (Duffy, 2013). Some abnormal speech characteristics include reduced rate, impaired speech intelligibility, and reduced phrase length (Cannito, 2014).

D'Innocenzo et al (2006) conducted a perceptual study to examine the intelligibility of a 29 year-old male with dysarthria as a result of a TBI from a motor vehicle accident (MVA) when he was 14 years old. The level of severity of the TBI is unknown. A speech sample determined the type of dysarthria to be mixed spastic-flaccid dysarthria. The patient exhibited a slow rate of speech, hypernasality, and poor speech intelligibility due to imprecise consonant articulation. Sentence transcriptions were completed by 120 naïve listeners, in which results determined a mean average of 35% intelligibility for this patient.

In a study conducted by Goozee et al (2000), one 19-year-old male, with mild spastic-ataxic dysarthria subsequent to severe TBI due to a railway accident, participated in Electromagnetic articulography (EMA) and perceptual assessments. A 26-year-old, healthy non-neurologically impaired male served as a control. Perceptual and physiological assessments revealed the patient with severe TBI had mild consonant imprecisions, and disturbances in the "control" of the tongue speed. EMA showed difficulty decelerating tongue movements for appropriate tongue to palate contact during consonant production.

Toshniwal and Joshi (2010) performed acoustical and perceptual analysis to examine the speech impairments of 3 subjects (ages: 24, 24, & 60) with mixed type dysarthria as a consequence of TBI. The level of severity was not revealed in the article. However, results determined slower speech rate, poor intelligibility, and affected prosody in patients with TBI compared to the healthy controls.

These studies provide evidence that dysarthria, post-TBI, can result in the reduced ability to communicate, which can profoundly influence an individual's daily communicative function (McAuliffe et al., 2010; Cannito, 2014). Therefore, it is crucial to include assessment procedures that are sensitive to deviant speech characteristics post-concussion given there is limited data.

These characteristics can be indicative of the severity level of impairment, which will influence RTP decisions (Cannito, 2014).

2.2 Neurocognitive testing

Researchers have postulate that neurocognitive tests are useful tools to identify an individual's cognitive deficits within 2-48 hours post-injury, as the potential for permanent cognitive deficits poses a great concern among the health care community (Cancelliere et al., 2014; King, Brughelli, Hume, & Gissane, 2014). Neurocognitive tests target cognitive domains such as, memory, attention, processing of information, and motor speed (Collins & Hawn, 2002). These computerized tests have been proven advantageous for many reasons: ease of test administration; ease of data retrieval; high sensitivity to subtle cognitive effects; measurement of multiple domains of performance and variability; and measurement of progress over time (King, Brughelli, Hume, & Gissane, 2014). Many studies have emphasized the use of baseline pre-injury and serial post-injury follow-ups. Baseline measures can be compared to post-injury results in order observe the cognitive effects of concussion (Covassin, Elbin, Ostrowski-Stiller, & Kontos, 2009).

The Immediate Postconcussion Assessment and Cognitive Testing (ImPACT) is a computerized neurocognitive battery designed for assessing neurocognitive functioning and concussion symptoms (Iverson, Brooks, Collins, Lovell, 2006; Covassin et al., 2009). The ImPACT provides data to assess and manage concussive injuries. The test has three main parts: demographic data, neuropsychological tests, and the Post-Concussion Symptom Scale (PCSS) (Schatz, Lovell, Collins, & Podell, 2005; ImPACT, Applications, Inc., 2016).

Van Kampen and colleagues (2006) examined the neurocognitive results from the ImPACT test and the postconcussive symptom score (PCS) of mildly concussed high school and

college athletes 2 days after the injury. The results were compared to the athletes' baseline performance and an age-matched nonconcussed athlete control group. The concussed group was comprised of 97 high school athletes and 25 college athletes (N=122). The control group was comprised 50 high school athletes and 20 college athletes (N=70). The study found that 93% of the concussed sample had significant increases in symptoms, as well as abnormal neurocognitive test results relative to their baseline data. In contrast, the control group had 0% of both abnormal neurocognitive results and symptoms.

A study conducted by Iverson, Lovell, & Collins (2002) investigated the validity measurements of ImPACT using 120 high school and college athletes. Results from the study revealed that concussed athletes reported more symptoms, and performances were worse on Memory and Reaction Time Indices (Schatz, Lovell, Collins, & Podell, 2005). Post-concussive symptoms were found to be significantly related to a decrease in performance on ImPACT Reaction Time, Verbal Memory, and Processing Speed Indices, which suggests the ImPACT is sensitive to the acute effects of a concussion (Iverson, Gaetz, Lovell, & Collins, 2004).

Broglio and colleagues (2007) report test-retest reliability of the ImPACT test of a study conducted by Iverson, Lovell, Podell, & Collins (2003). ImPACT reliability was examined in 49 high school and collegiate athletes, in which baseline measures were compared to the athletes' 14-day follow-up. Pearson correlation coefficient determined the following reliability results: .54 (memory); .63 (reaction time); and .76 (processing speed). These results fall within an acceptable range for clinical interpretations (Iverson et al., 2003).

In another study conducted by Iverson, Lovell, & Collins (2003), the stability of test scores and the calculation of reliable change confidence intervals for test-retest difference was evaluated. The results of the study determined that the test battery served to be sensitive to the

acute effects of concussion, and a large percentage of athletes showed substantial changes in functioning within the first few days post-injury.

2.2.1 Interpreting the ImPACT assessment

The ImPACT test battery consists of 6 modules that evaluate attention, memory, visual processing speed, and reaction time, which yield composite scores that provide information regarding different cognitive domains (Covassin et al., 2009; Moser, Glatts, & Schatz, 2012; ImPACT, Applications, Inc., 2016). Each module contributes values to multiple composite scores that are automatically computed by ImPACT. The individual's result for each composite score is then compared to baseline performance, or normative data provided by ImPACT. Table 2.1 provides a listing of the ImPACT modules and a description of neurocognitive abilities assessed. From these 6 tests, 4 separate composite scores are generated: verbal memory, visual memory, visual motor speed, and reaction time.

Table 2.1 ImPACT Neurocognitive Test Battery

Test Module	Ability Areas
Word Memory	Immediate and delayed memory for words
Design Memory	Immediate and delayed memory for designs
X's and O's Symbol Match	Attention, concentration, working memory, reaction time
Symbol Match	Visual processing speed, learning and memory
Color Match	Focused attention, response inhibition, reaction time
Three Letters	Attention, concentration, working memory, visual-motor speed
Composite Score	**Contributing Score**
Verbal memory	Averaged percentage correct scores for the Word Memory (learning and delayed), Symbol Match memory test, and Three Letters Memory test
Visual memory	Averaged percentage correct scores for the Design Memory (learning and delayed) and the X's and O's test
Reaction time	Mean time in milliseconds for the X's and O's (mean counted correct reaction time), Symbol Match (mean weighted reaction time for correct responses), and Color Match (mean reaction time for correct response)
Visual motor processing speed	X's and O's (mean correct distracters), Symbol Match (mean correct responses), and Three Letters Memory (number of correct numbers correctly counted)

Accurate interpretation of the post-concussion results can provide the clinician with valuable information in regards to the athlete's improvements or declines in function compared to baseline performance or normative data. ImPACT composite scores are designed to supplement return-to-play decisions using evidence-based data to support clinical judgments (Iverson, Lovell & Collins, 2003).

2. 3 Oral diadochokinesis (DDK)

A traditional task used to assess motor speech capabilities is oral diadochokinesis (DDK). It is a quantitative and qualitative examination of speech that provides insight into speech subsystem impairments in dysarthria (Blumberger, Sullivan, & Clement, 1995). These tasks measure the repetitive rate of a certain consonant-vowel syllable, and the repetitive rate of changing consonant-vowel syllable, respectively (Ergun & Oder, 2008). Quantitative results from DDK rates serve as a sensitive indicator to determine the presence of neurological impairment and is used to monitor changes over time (Wang, Kent, Duffy, Thomas, & Weismer, 2004; Gadesmann & Miller, 2008). The diadochokinetic rate is quantified by the evaluation of two different types of repetitive syllable motion rates: alternating motion rate (AMR) and sequential motion rate (SMR).

Alternating Motion Rates (AMRs) measure the speed and regularity of the rapid articulatory movements during consonant-vowel syllable production (Duffy, 2014). The task includes repetitions of 3 individual syllables: /puh/, /tuh/, /kuh/. When repetitions of /puh/ are completed, the task is repeated for /tuh/ and /kuh/. These syllables assess articulatory place and manner during consonant production (Wang et al., 2004; Duffy, 2014).

Sequential Motion Rates (SMR) measure the rate at which the syllables are produced rapidly from one articulatory placement to another in proper sequence (Ergun & Oder, 2008;

Duffy, 2014). The task is characterized by repeating a sequence of three different syllables continuously: /puhtuhkuh, puhtuhkuh, puhtuhkuh…/ (Duffy, 2014). In addition, Ziegler (2002) examined DDK tasks in patients with dysarthria and apraxia of speech, from varying etiologies, and found slowed DDK performances relative to the control group. From this study, Ziegler (2002) also suggests the use of DDK tasks as a diagnostic index of speech impairment, as this task is considered the most "speechlike" because it is the production of real syllables.

Studies show that speech can be affected after sustaining a brain injury. Considering the frequency of brain injuries, coupled with what is known about cellular damage upon concussive injury, it would appear appropriate to utilize DDK to investigate the severity of motor speech performance post-concussion (Blumberger, Sullivan, & Clement, 1995).

In a study conducted by Wang et al (2004), AMR tests were used in seven patients with traumatic brain injury (TBI) of varied etiologies with unspecified levels of severity. Acoustic quantitative analysis revealed specific information regarding the motor speech limitations of patients with TBI. The results of the analysis indicated that patients with TBI had a slower rate of syllable repetition for AMRs due to both lengthened syllables and intersyllable gaps, which were postulated to be due to the slowing of articulatory movements and reduced force (Wang et al., 2004).

2.4 Speech rate and sentence intelligibility

Dysarthria has been documented to occur in about one-third of those with traumatic brain injury (McAuliffe et al., 2010; Duffy, 2013; Cannito, 2014). Typically, dysarthria causes disturbances in the articulatory movements that effect intelligibility and rate of speech. The Assessment of Intelligibility in Dysarthric Speakers (ASSIDS) is a standardized test and is most widely used for its ability to measure intelligibility, speaking rate, and communicative efficiency

for those with dysarthria (Goozee et al., 2000; Morgan, Liegeois, & Occomore, 2007; Cannito, 2014; Duffy, 2014;).

The Sentence Intelligibility Test (SIT) is an updated computerized version of the intelligibility measures of the ASSIDS assessment (Yorkston, Beukelman, & Tice, 1996). This measures: overall intelligibility-percentage of words understood by the listener; the total number of words produced and the words per minute (WPM); the accuracy of the words produced and intelligible words per minute (IWPM); and the rate of intelligible speech (Communication Efficiency Ratio) (CER). Scores for normal speakers (N= 10 males and 10 females) when performing this task is 100% for intelligibility and 190 IWPM (Yorkston & Beukelman, 1981).

In a study conducted by Cahill, Murdoch, & Theodoros (2005), the sentence task from the ASSIDS was used to examine the performance of 24 participants with acquired severe TBI due to CHI. Four variables of the ASSIDS were administered to include: sentence intelligibility, WPM, IWPM, and CER. The results revealed the individuals with dysarthria (DTBI group) displayed significantly lower values than those without dysarthria (NDTBI) for all variables measured.

Goozee et al (2000) administered the single word and sentence intelligibility task to a 19-year-old male with dysarthria post- severe TBI. The quantification of the speech intelligibility and speaking rate revealed a mean speech intelligibility for single word was 87% and 98.61% for the sentence level, 166 words per minute (WPM), and 164 intelligible words per minute (IWPM). The results, however, indicate a lower mean IWPM than the mean rate of intelligibility for normal speakers (190 IWPM) (Yorkston & Beukelman, 1981).

There is limited research on the use of the ASSIDS- Sentence Intelligibility Test (SIT) on SRC. The Hewitt (2015) study reported on the effects of SRC on SIT. Results showed mean

intelligibility for the SRC group was 97.88 ± 1.71 in comparison to 98.29 ± 1.55 for the control group. However, no statistical differences were found for that task (Hewitt, 2015). This current study will replicate the Hewitt (2015) study and employ the computerized updated version of the SIT to obtain means for speech intelligibility, the rate of speech, and communicative efficiency.

2.5 Motor limb tasks

Available research on the slowing of motor execution has traditionally been attributed to diffuse axonal injury (DAI) that typically occurs in moderate-severe TBI (McNamee,Walker, Cifu & Wehman, 2009). Some research postulates that the slowing of movement execution can be attributed to DAI that can also occur in mTBI (Gagnon, Forget, Sullivan, Friedman, 1998; Monte, Geefen, May, McFarland, Heath, Neralic, 2005; De Beaumont, Theoret, Mongeon, Messier, Leclerc, Tremblay, Ellemberg, and Lassonde, 2009).

Monte and colleagues (2005) examined 64 mTBI cases (mean age of 24.42 for males and 26.86 for females), within 24 hours of the injury, using diadochokinesia tasks as a measure of motor speed. The performances for the mTBI group showed an overall slowing of motor speed in patients with mTBI compared to the control group.

Few studies examining motor limb effects for SRC are available. However, Dolan (2013) and Hewitt (2015) conducted studies utilizing finger repetition tasks to measure the effect of motor limb, in collegiate athletes with SRC compared to a healthy control group. Both studies found statistical differences between groups. Dolan (2013) found statistically significant differences in finger repetition task between the athletes post-SRC in comparison to a control group. The overall mean duration time for the athletes post-SRC was 8.14 seconds ± 2.28 in comparison to 5.78 seconds ± 1.25 for the control group. Hewitt (2015) also found statistically significant differences in finger repetition task between the athletes post-SRC in comparison to

the control group. The overall mean duration time for the athletes post-SRC was 8.01 seconds ± 1.66 in comparison to 6.86 seconds ± 1.60 for the control group. In addition, Hewitt (2015) investigated movement execution initiation time and found a statistical difference between the SRC group and the control group. The total mean duration time for the SRC was 172.44 milliseconds ± 136.97 for the SRC group in comparison to 101.11 milliseconds ± 29.68 for the control.

For the purpose of this replication study, motor limb tasks will include a finger repetition task and movement execution initiation time task.

2.6 The motor system- cortical components

Gooze et al (2012) have noted that speech impairments, secondary to TBI, may be due to widespread neuronal damage within the motor system that consequently affect skilled motor movement necessary for speech articulation. Speech production includes fine motor skills that require the regulation of both accuracy and speed, in which damage to the motor system can disturb its function, causing motor speech problems such as, dysarthria. Many researchers believe the deficits in speech impairment and motor slowing are due to the DAI, as a result of the shearing forces generated by the acceleration/deceleration of the brain (Barrow, Collins, Britt, 2006; Morgan, Leigeois, & Occomore, 2007; Ergun & Oder, 2008). As findings continue to attribute speech and motor deficits to widespread neuronal damage in mTBIs, it is important to discuss the involvement of the motor system in SRC.

The motor cortex is comprised of the primary cortex, premotor cortex, and supplementary motor area (SMA). The primary motor cortex generates signals to execute movement and the secondary motor cortices such as the posterior parietal cortex, the premotor cortex, and the supplementary motor area, sends transmissions to the primary motor cortex (Schwerin, 2013).

Within these cortical areas are pathways for neuronal communication: direct pathway (movement execution) and indirect pathway (movement inhibition) (Duffy, 2013). The direct pathway receives input from the premotor cortex and SMA. The pyramidal tract is comprised of direct pathways, in which there are two tracts: corticobulbar (speech) and corticospinal (limb) (Culbertson, 1999). The corticobulbar tract connects with motor neurons of the brainstem that influence cranial nerves that stimulate movement for the face, jaw, tongue, and pharynx (Kandel, Schwartz, Jessell, 2000; Duffy, 2013). The corticospinal tract is mostly involved with the control of fine, digital movement (Swenson, 2006). Therefore, through input from the cortical areas voluntary movement can be executed (Duffy, 2013).

The acceleration and abrupt deceleration of the brain that occurs upon impact can cause specific speech and language difficulties that are secondary to a diffuse injury, which can manifest as difficulties with speaking rate and speech intelligibility (Drummond & Boss, 2004). Researchers agree that widespread injury to any of these cortical areas can interrupt the interactions of the neurons that are necessary to execute controlled movements, such as motor limb movement and speech production (Gaetz el al., 2000; Drummond & Boss, 2004; Schwerin, 2013; Duffy, 2013).

2.7 Brain regions involved

It is important to recognize that the primary motor cortex controls both motor limb and motor speech movements. However, the execution of movement is exclusive to different regions of the brain, as they are different systems. Kent (2003) highlighted the distinctiveness of the speech production system from limb muscles.

Motor speech movements involve the ventral portion of the sensorimotor cortex (vSMC), in which neurons project via the corticobulbar tract that innervate the muscles of the upper face,

jaw, oropharynx, and vocal tract through for articulatory movement (Conant, Bouchard, & Chang, 2014; Breshears, Molinaro, Chang, 2015). In an fMR study investigating motor planning on execution, investigators found activation of many different networks that support motor speech, including the vSMC, anterior-superior temporal cortex, SMA, basal ganglia, cerebellum, and the thalamus (Smith, 2010). Speech production requires volitional movement, which is accomplished by using of motor planning and programming, which depends on the influence of the activation pathways (Duffy, 2013).

In comparison to motor speech movements, motor limb movements are innervated by neurons projected from the dorsal sensorimotor cortex (dSMC), which are innervated by the corticospinal tract (Conant, Bouchard, & Chang, 2014; Breshears, Molinaro, Chang, 2015). The corticospinal tract provides input to the necessary muscles to execute fine, skilled movements. In an article by Walker and Pickett (2007), several studies investigating motor deficits, 12-16 months post-TBI, found deficits in fine motor skills, speed and coordination, and subclinical bradykinesia (Chaplin, Deitz, Jaffe, 1993; Haaland,Temkin, Randahl,Dikmen,1994; Kuhtz-Buschbeck, Hoppe, Gölge, Dreesmann, Damm-Stünitz,Ritz, 2003; Walker &Pickett, 2007).

The purpose of this study is to investigate motor speech and motor limb movements following a sport-related concussion. The following behaviors will be measured: oral DDK, intelligibility, speech rate, movement execution initiation time, and finger repetition task.

The first objective of the current study is to replicate and extend previous research: Dolan (2013) and Hewitt (2015). Dolan (2013) evaluated motor speech parameters in SRC athletes that included SMRs and a finger repetition task. Hewitt (2015) replicated that study and extended it by increasing the sample size in both groups and investigated additional speech measures that included speech rate, speech intelligibility, and AMRs. Additionally, that study aimed to

determine if there is a statistical correlation between DDK tasks, movement execution initiation, and finger repetition between the groups. Data from Dolan (2013) and Hewitt (2015) will be included with data collected with the current study data for two reasons: 1) Increase the number of healthy controls to create normative data for speech rate, speech intelligibility, oral DDK, movement execution initiation task, and finger repetition; and 2) Increase the statistical power in the SRC group. The second objective of this current study is to determine if there is a relationship between ImPACT composite scores and oral DDK mean duration time, speech intelligibility, speech rate, movement execution initiation task, and finger repetition between the groups.

This study is an experimental group design that is comprised of an SRC group of athletes with a sports related concussion, and a control group composed of healthy non-concussed individuals. Both groups participated in the same battery of assessments that include: UTEP Concussion Protocol, oral DDK, sentence intelligibility task, movement execution initiation time, and a finger repetition task. The following behaviors will be analyzed for each participant: oral DDK (mean syllable duration time and total mean duration time), speech rate (words per minute (WPM), intelligible words per minute (IWPM), syllables per minute (SPM), speech intelligibility, movement execution initiation time (milliseconds), and a finger repetition tasks (seconds). The research questions and hypotheses are the following:

1. Is there a statistically significant difference in the mean syllable duration of the oral diadochokinetic (DDK) speech tasks (AMRs and SMRs) between the SRC group and the control group?

   Hypothesis: The SRC group will have slower DDK mean syllable duration in comparison to the control group.

2. Is there a statistically significant difference in intelligible words per minute (IWPM) on the standardized Sentence Intelligibility Test (SIT) between the SRC group compared to the control group?

   Hypothesis: The SRC group will have slower IWPM in comparison to the control group.

3. Is there a statistically significant correlation between IWPM and the oral DDK mean syllable duration times between the SRC group and the control group?

   Hypothesis: There will be a strong relationship between the oral DDK mean syllable duration times and IWPM between the SRC group and the control group.

4. Is there a statistically significant difference in mean duration times on movement execution initiation and finger repetition tasks between the SRC group and the control group?

   Hypothesis: The SRC group will have lower mean duration times in comparison to the control group.

5. Is there a statistically significant correlation between oral DDK mean duration times and total mean duration of movement execution initiation and finger repetition tasks between the SRC group and the control group?

   Hypothesis: There will be a statistically significant correlation between oral DDK duration times, movement execution initiation and finger repetition tasks across both groups.

6. Is there a statistically significant correlation between ImPACT composite scores (verbal memory; visual memory, visuomotor speed, and reaction time) and oral DDK mean syllable duration times between the SRC group and the control group?

Hypothesis: There will be a statistically significant correlation between ImPACT composite scores and oral DDK mean duration times across both groups.

7. Is there a statistically significant correlation between ImPACT composite scores and IWPM between the SRC group and the control group?

   Hypothesis: There will be a statistically significant correlation between ImPACT composite scores and the IWPM across both groups.

8. Is there a statistically significant correlation between ImPACT composite scores and total mean duration of the motor limb tasks between the SRC group and the control group?

   Hypothesis: There will be a statistically significant correlation between ImPACT composite scores and total mean duration of the motor limb tasks across both groups.

Chapter III: Methods

The study proposal was reviewed and approved by The Institutional Review Board (IRB) at the University of Texas at El Paso (UTEP). All research was conducted in accordance with the approved submission of the proposal. The IRB reference code number for this study is 552011-3.

3.1 Participants

A total of 23 participants were recruited for the SRC group, and 104 participants were recruited for the control group. Out of the 23 participants for the SRC group, 18 participants were retrospective data from Dolan's (2013) study and Hewitt's (2015) study. One participant from the SRC group was excluded from the study due to eligibility requirements. In the 104 participants from the control group, 3 were excluded from the study due to eligibility requirements. Therefore, the total number of participants in this study was 101 for the control group, in which 50 were from Hewitt's (2015) study. Data for the control group was later reduced to 22 participants by matching age and gender as closely as possible to the SRC group. Table 4.6 provides a summary of means and standard deviations for the control group (N=101) before it was age-matched and gender-matched for normative data. Table 4.7 provides a summary of the demographics of healthy non-concussed individuals (N=101) for normative data.

The SRC group consisted of 22 athletes diagnosed with a concussion within one-month of the study testing. Of the 22 athletes, 18 participants were athletes who sustained a concussion at the middle school, high school, and collegiate level. One athletic participant sustained a concussion as a motor vehicle accident (MVA) (Hewitt, 2015). Table 3.1 provides a detailed summary of the demographics of the participants in the SRC group.

The inclusion criteria for the SRC group included the following: a current diagnosis of a concussion, no history of speech or language disorders, no hearing loss, no history of drug/alcohol abuse, no previous history of psychiatric illness, learning disability, neurological history (seizure, central nervous system neoplasm, or brain tumor) or TBI unrelated to concussion.

Table 3.1 Demographic information of the SRC group.

Subject	Gender	Age	Concussion Type and Level	History of Concussion	Post Injury	Study
201	F	23	MVA	0	3 days	Hewitt (2015)
202	M	13	Sport: Football (Middle School)	3	7 days	Hewitt (2015)
203	F	21	Sport: Cheerleading (Collegiate)	0	3 days	Hewitt (2015)
204	M	18	Sport: Ice Hockey (Semi-Professional)	2	1 day	Hewitt (2015)
205	F	18	Sport: Cheerleading (Collegiate)	2	2 days	Hewitt (2015)
206	M	20	Sport: Cheerleading (Collegiate)	3	4 days	Hewitt (2015)
207	M	17	Sport: Football (High School)	1	4 days	Hewitt (2015)
208	M	22	Sport: Football (Collegiate)	0	7 days	Hewitt (2015)
209	M	17	Sport: Football (High School)	3	32 days	Hewitt (2015)
210	M	16	Sport: Football (High School)	0	33 days	Hewitt (2015)
211	M	22	Sport: Football (Collegiate)	1	2 days	Dolan (2013)
212	F	18	Sport: Basketball (Collegiate)	0	1 day	Dolan (2013)
213	F	19	Sport: Basketball (Collegiate)	1	6 hours	Dolan (2013)
214	M	18	Sport: Ice Hockey (Semi-Professional)	3	4 days	Dolan (2013)
215	M	19	Sport: Ice Hockey (Semi-Professional)	3	12 days	Dolan (2013)
216	F	19	Sport: Cheerleading (Collegiate)	0	6 days	Dolan (2013)
217	M	19	Sport: Ice Hockey (Semi-Professional)	0	3 days	Dolan (2013)
218	F	19	Sport: Dance (Collegiate)	0	2 days	Dolan (2013)
219	F	16	Sport: Basketball (High School)	1	5 days	Phan (2016)
220	F	20	Sport: Volleyball (Collegiate)	0	8 days	Phan (2016)
221	F	18	Sport: Soccer (Collegiate)	1	10 days	Phan

						(2016)
222	M	15	Sport: Football (High School)	3	5 days	Phan (2016)

The control group was comprised of 22 individuals, closely age-matched and gender-matched with the SRC group who had not reported a concussion within the last 12 months. Participants were included if they satisfied the following criteria: no history of speech or language disorders, no hearing loss, no history of drug/alcohol abuse, no previous history of psychiatric illness, learning disability, neurological history (seizure, central nervous system neoplasm, or brain tumor) or TBI unrelated to concussion.

Independent-samples *t*- test showed no statistically significant differences between groups for the variables: age, gender, adolescents, and adults. However, the independent-samples *t*- test revealed a statistically significant difference between groups for the number of participants involved in sports. Table 3.2 provides a detailed summary of the demographics of the control group. Table 3.3 provides the means and standard deviations for demographic data for both groups.

Table 3.2 Demographic information for the control group.

Subject	Gender	Age	Sport	Medical History	Study
101	M	13	Non-Athlete	None	Phan (2016)
102	M	13	Non-Athlete	None	Hewitt (2015)
103	M	13	Non-Athlete	None	Phan (2016)
104	F	15	Soccer	None	Hewitt (2015)
105	F	15	Track & field	None	Hewitt (2015)
106	F	15	Non-Athlete	None	Phan (2016)
107	M	15	Track & field	None	Phan (2016)
108	F	16	Non-Athlete	None	Hewitt (2015)
109	F	17	Non-Athlete	None	Hewitt (2015)
110	M	18	Non-Athlete	None	Hewitt (2015)
111	F	18	Non-Athlete	None	Hewitt (2015)
112	F	18	Non-Athlete	None	Hewitt (2015)
113	M	19	Non-Athlete	None	Hewitt (2015)
114	F	20	Non-Athlete	None	Phan (2016)

115	M	20	Non-Athlete	None	Hewitt (2015)
116	M	20	Non-Athlete	None	Phan (2016)
117	F	20	Non-Athlete	None	Phan (2016)
118	F	21	Non-Athlete	None	Phan (2016)
119	F	21	Volleyball	None	Hewitt (2015)
120	M	22	Non-Athlete	None	Hewitt (2015)
121	F	22	Non-Athlete	None	Hewitt (2015)
122	M	23	Golf	None	Phan (2016)

Table 3.3 Summary of demographic information for both groups

Characteristics	**Control Group**	**SRC Group**
Age	17.91 (± 3.14)	18.45 (± 2.36)
Gender	10 Males, 12 Females	12 Males, 10 Females
Avg. days post-injury	N/A	7.04 (± 8.37)
Adolescents (13-17 yrs.)	9	6
Adults (18-23 yrs.)	13	16
Sports	6	21*

Standard deviations are represented in parenthesis.
Asterisk shows significance at the .05 level or less

3.2 Participant recruitment

Participants in the SRC group were recruited from the UTEP Concussion Management Clinic (CMC). Each individual was diagnosed with a concussion by the athletic trainers, and/or physician prior to being referred to the clinic. Upon completion of the protocol, the participant was given a $25 gift card, which was funded by CMC.

Participants in the control group were recruited from various programs within the Department of Rehabilitation Sciences, at the University of Texas at El Paso. Adolescents were recruited by students from UTEP- mostly friends of younger siblings. Upon completion of the protocol, the participant was given a $10 gift card, which was also funded by CMC.

3.3 Setting

The study was conducted at the UTEP Speech Hearing, and Language Clinic, as well as the UTEP Concussion Management Clinic. The Speech Hearing, and Language Clinic rooms were utilized as a place for participants to review the study procedures, to complete the medical history forms, consent forms, and to provide recommendations for those who have sustained a concussion. Each participant was provided with details regarding the procedures of the study and was also made aware of their right to withdraw from the study at any time. Additionally, each individual completed a hearing screening. Acoustic recordings of all speech tasks (DDK and SIT) were obtained in a sound-treated booth to ensure consistent test reliability.

3.4 Procedures

Prior to the initiation of testing, the procedures of the study were explained to each participant and consent forms were completed. Additionally, participants completed the following procedures in order to be included in the study: (a) medical history questionnaire and (b) hearing screening. Participants were automatically dismissed from the study if the above criterion was not satisfied. The entire procedure required one testing session of 2.5 hours in duration. Both the SRC group and the control group completed the same testing protocol. The protocol included UTEP CMC assessment battery, motor speech, and motor limb tasks. The UTEP CMC assessment procedures are described in detail in this chapter. However, data will only report motor speech and motor limb outcomes, as this is the focus of this study.

Once participants were determined to be eligible for study, the following protocol was administered (c)[1]*Post-injury Concussion Questionnaire (in SRC group only); (d)*Romberg test; (e)[2] Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT); (f) handedness questionnaire; (g) Pitt and Posttraumatic stress disorder questionnaire; (h) 3-D shape copying

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[1] *Represents tasks that were exclusive to the individuals in the SRC group.
[2] Represents the randomization of tasks for (k)-(m).

task; (i) Verbal Fluency Assessment; (j) Nintendo-Wii Basic Balance Test; (k) Oral diadochokinetic task (DDK); (l) Sentence Intelligibility Task (SIT); and (m) movement execution initiation time task and a finger repetition task.

To replicate the procedures from the Hewitt (2015) study, two levels of randomization were utilized to control for fatigue. The first level of randomization included the administration of DDK, SIT, and motor limb tasks either at the beginning or the end of the protocol. The second level of randomization occurred within the DDK tasks, and four conditions were created. The first condition required the investigator to carry out DDK tasks at the beginning of the entire protocol to elicit SMRs first and then AMRs, or as a second condition, to elicit AMRs first and then SMRs. The third condition required the investigator to carryout DDK tasks at the end of the UTEP CMC battery, and to elicit SMRs first and then AMRs, or as a fourth condition, to elicit AMRs first and then SMRs. Therefore, DDK tasks were either given at the beginning of the protocol and then randomized by eliciting first the sequential motion rates (SMRs) and then the alternating motion rates (AMRs) or vice versa, or DDK tasks were given at the end of the protocol and randomized by eliciting first the SMRs then the AMRs or vice versa.

3.4.1 UTEP CMC protocol

Hearing Screening

Each participant was screened according to American Speech-Language Hearing Association standards in both ears at four different frequencies: 500Hz, 1000Hz, 2000Hz, and 4000Hz, at 25 dB HL. If the participants failed to respond to any of the four frequencies, in either ear, they were excluded from the study and a referral was made to their primary doctor. For the current study, all participants met this requirement.

Post-Injury Interview

Each participant in the SRC group underwent a post-injury interview with the examiner to obtain detailed information regarding the current concussion and any previous concussions. Participants' responses were recorded on the post-injury form. The examiner obtained the following information relative to the concussion(s): date of concussion(s); a detailed description of the injury described by the athlete and/or parent/coach; loss of consciousness; and recall of events: pre and post-concussion. In addition, participants were asked to describe and identify the exact location of the injury (relative to the head). The examiner then orally read a list of symptoms and asked the patient to rate the symptom on a Likert-like scale (1-6: one being the least severe and 6 the most severe) (adopted from ImPACT, 2012).

Romberg Test

The Romberg Test is a neurological test for balance. This test was administered only to individuals in the SRC group. According to Khasnis & Gokula (2003), proprioception dysfunction, which is a common occurrence with individuals with a concussion, can be masked using other senses such as visual and vestibular feedback. The instructions for this task required the participant to face a certain direction with their eyes closed, stand up straight, and with their feet together, and arms forward (at chest and shoulder level). First, the examiner stood behind the participant and observed their balance. If the participant was observed swaying or failing to maintain balance, the Romberg test was immediately discontinued and the test was considered positive. If the participant did not demonstrate signs of imbalance, the Romberg test continued with the examiner slightly pushing the participant forward and then again from the right side and the left side. After each push, the examiner observed for signs of swaying or any failure to maintain balance. If no swaying or imbalance was observed, then the Romberg test was considered negative (Khasnis & Gokula, 2003).

ImPACT –Immediate Post-concussion Assessment and Cognitive Testing

For the administration of this assessment, each participant was seated at a desktop computer in a quiet room absent from noise and free from outside distractions. Each participant was provided with standardized verbal instructions for the task. Once the standardized instructions were provided, each participant was to complete the following sections: demographic and background information; self-reported symptoms- the Post-Concussion Symptom Scale; and the Neurocognitive test. The neurocognitive section itself is comprised of 5 subsections: Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. The entire ImPACT protocol approximately took up to 30 minutes for healthy non-concussed individuals, and up to 40 minutes for individuals with a concussion. Additionally, the entire test was administered and monitored under the supervision of the examiner. Upon completion of the test, descriptions and derivations of each composite score were automatically generated in the ImPACT Clinical Report.

Handedness Questionnaire

This handedness questionnaire was administered to both groups. The target of this task was for individual to reflect on which hand they use to conduct (or carry out) specific tasks. The Annett (1970) questionnaire was modified to simplify the understandability of some of the tasks. This questionnaire was used to determine whether a participant was right/left-handed or ambidextrous.

Pitt and Post-Traumatic Stress Disorder (PTSD) Questionnaires

The Pitt and PTSD questionnaire was given to both groups. The Pitt questionnaire was administered to determine the individual's ability to orient themselves with the date, month, day of the week, and current location. The PTSD questionnaire aimed to gain insight on the

individual's current level of stress and feelings caused by the concussion. The questions included the following: occurrences of nightmares; flashbacks; feelings of detachment; fear; anxiety; and stress as a result of the injury.

3-D Shape Assessment

The 3-D shape assessment was administered to both groups. This task required participants to copy and draw five different 3-D objects that varied in complexity. If the baseline of these drawings were obtained, a comparison was made between both drawings: pre- and post-concussion. Otherwise, the drawing was compared to the individual's subsequent drawing from the follow-up appointment. This assessment was used to detect any visuoperceptual impairments of any kind, which may be a result of damage to the right hemisphere (Brookshire, 2007).

Verbal Fluency Assessment

A verbal fluency assessment was administered to both groups. According to Tombaugh, Kozak, & Rees (1999), phonemic and semantic verbal fluency measures are sensitive to lesions in the frontal lobe, temporal lobe, and caudate nucleus. Each participant was instructed to orally generate words within a 1-minute time frame for the letters F, A, S, J, and R (phonemic word fluency). In addition, each participant was asked to generate the names of animals (semantic fluency) also within 1-minute. The examiner recorded the responses and added the number of correct responses, excluding: any proper names, repetitions, the same word with a different suffix, or wrong items. Percentile scores were derived using normative data from the Tombaugh, Kozak, & Rees (1999) study, and compared between both groups.

Nintendo- Wii Basic Balance Test

This assessment was administered to both groups to assess the individual's balance. The Nintendo Wii Balance board was placed approximately six feet from the television screen. The

examiner orally read the directions to each participant to ensure the participant understood the instructions. The task required the participant to complete five balancing tasks within 30-seconds with levels of difficulty increasing with each level. Upon completion, the Nintendo- Wii Basic Balance test automatically provided the results for each participant and the examiner recorded the data.

3.5 Speech tasks

3.5.1 Oral diadochokinetic task

Each participant from both groups was seated in a chair in a sound-treated booth. The Computerized Speech Lab (CSL), model 4500, by Kay Elemetrics, with a sampling Hz of 11025, was utilized to record the DDK tasks for each participant. A microphone (model C420) was positioned one inch from the center of the participants' lips. The investigator provided oral standardized instructions for the task, and also provided a sample model of the task. Participants were instructed to produce a sequence of the syllables as accurately and rapidly as possible. Each participant received three practice productions of the sequence to ensure that the instructions were understood thoroughly before the task began. In this study, tasks included both AMR and SMR syllable repetitions. A fixed number of syllable occurrences were elicited for each task. Therefore, a total mean duration (with and without gap durations) and mean syllable duration was calculated, rather than rate.

Alternating Motion Rates (AMR)

For this task, the participants were instructed to take a deep breath and utilize that breath in the production of /puh/, /tuh/, /kuh/ as rapidly and accurately as possible without stopping. For example, the participant produced /puh/ as correctly and rapidly as possible, in a single continuous breath until the investigator obtained approximately 12 syllable productions and then

instructed the participant to stop. A fixed number of ten syllables were used to calculate a mean syllable duration time and a total mean duration time using the CSL program (see acoustic analysis for explanation of analysis). The instructions and process remained the same for the /tuh/ and /kuh/.

Sequential Motion Rates (SMR)

For this task, the participants were instructed to take a deep breath and utilize that breath in the production of a trisyllable of /puhtuhkuh/ also as rapidly and accurately as possible without stopping. For example, the participant produced /puhtuhkuh/ as correctly and rapidly as possible, in a single continuous breath until the investigator obtained approximately 12 trisyllables and then instructed the participant to stop. A fixed number of ten syllable productions were also used to calculate a mean trisyllable duration time and a total mean duration time using the CSL program (see acoustic analysis for explanation of analysis).

3. 6 Sentence intelligibility task (SIT)

The SIT computerized standardized assessment was utilized to analyze speech sentence intelligibility, sentence duration, accuracy, and the speaking rate of 11 randomized sentences of varying word lengths (Yorkston, Beukelman, and Hakel, 1996). The investigator administered this assessment according to the standardized protocol. Each sentence was read aloud by the investigator, and then participants were asked to repeat the sentence. Each sentence increased with complexity; therefore, participants were allowed to practice these sentences. If during the recording the participant displayed difficulty remembering the sentences, the participant was re-recorded, as speech rate was the area of focus rather than information recall Marantz, PMD670, digital compact flash portable recorder was used to record all sentence productions.

3. 7 Motor limb assessments

3. 7.1 Finger repetition task

Each participant was asked to use the dominant hand to alternate finger movements by touching the thumb to the pointer finger, followed by the thumb to the middle finger, and then by the thumb to the ring finger. These participants were instructed to be as accurate and quick as possible. To ensure individuals understood the task, each participant was allowed to practice three times. All productions were video recorded, but only ten productions of the task (the 2nd production to the 11th production), were timed. This ensured that recorded productions were without error. This task was video recorded using the Photobooth application software, version 8.0, via a 2010 Macbook Pro.

3. 7. 2 Movement execution initiation task

Each participant from both groups was given a handheld digital stopwatch and was instructed to start and stop the stopwatch as quickly and accurately as possible using the dominant hand. To ensure individuals understood the task, each participant was allowed to practice three times. Each individual participated in three separate trials that were video-recorded using the same software listed above. The results for each of the three trials were averaged to obtain one movement execution initiation time.

3.8 Analysis

3.8.1 Acoustic analysis

The Computerized Speech Laboratory (CSL), model 4500, by Kay Elemetrics was used to record and collect data for speech samples. The CSL was also utilized to analyze and calculate the DDK duration times. Like the Hewitt (2015) study, this current study reports the mean syllable duration and total mean duration rather than rate, as there was a fixed number of syllable occurrences elicited for each DDK task.

In the analysis of each DDK task, a combination of waveform and spectrogram displays were utilized to examine 10 repetitions of both AMRs and SMRs. Both the waveform and spectrogram display were aligned on the CSL screen, with both window displays adjusted to the same window size, and cursors were linked. The waveform display and the audio perception of the examiner were the primary source of analysis (Hewitt, 2015). The spectrogram display was used as a secondary source of analysis and served as an aid to help identify onset and/or offset of a syllable (Hewitt, 2015).

On the waveform display, a 0.3-second window expansion was utilized both at the beginning and at the end of each DDK task. This method was consistent to the Hewitt (2015) study and was utilized to ensure consistency in analyzing the onset of the initial syllable and the offset of the final syllable. Out of twelve productions, the beginning syllable and the last syllable of each trial were omitted, and measurements began with the 2nd production, followed by the subsequent syllable, up to the 11th production. Therefore, only ten productions were measured for each DDK task.

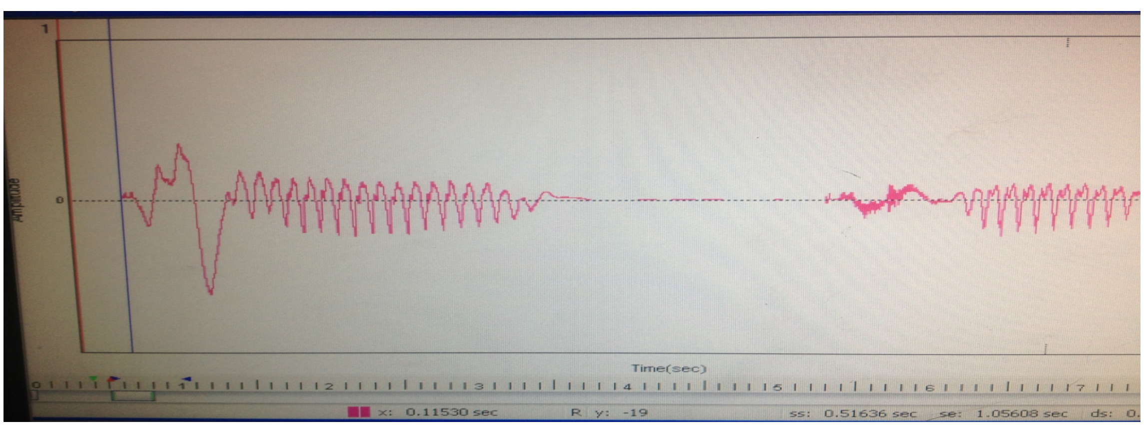

Illustration 3.1 Shows the 0.3-second expansion to measure the onset of a tri-syllable sequence (Hewitt, 2015)

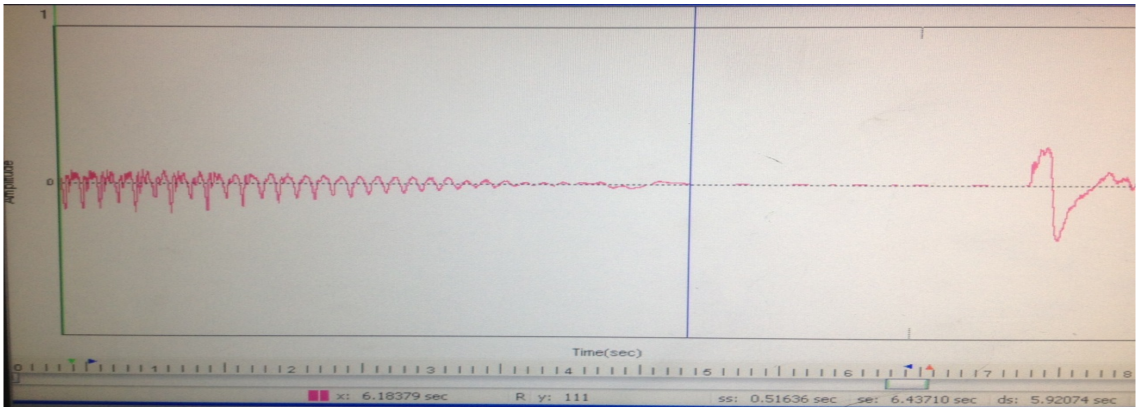

Illustration 3.2 Shows the 0.3 second expansion to measure the offset of a tri-syllable sequence (Hewitt, 2015)

In the SMR task, the examiner placed a cursor on the second onset of the /puh/ syllable and the other cursor on the final offset of the /kuh/ syllable of the 11th syllable sequence. As previously stated, a 0.3-second window expansion was set to measure the onset and offset of the entire sequence (see illustration 3.1 and 3.2). Upon manual placement of beginning and end cursors, the CSL provided the total time for all ten /puhtuhkuh/ tri-syllable sequences, with gap durations, in seconds. In addition, the window expansion was then set to 0.8-seconds, for the SRC group, and 0.5-seconds for the control group, to measure the onset and offset of each /puhtuhkuh/ tri-syllable sequence, one at a time. Cursors were manually set at the beginning and end of each /puhtuhkuh/ sequence (see illustration 3.3), in which the CSL provided the total duration time for each tri-syllable.

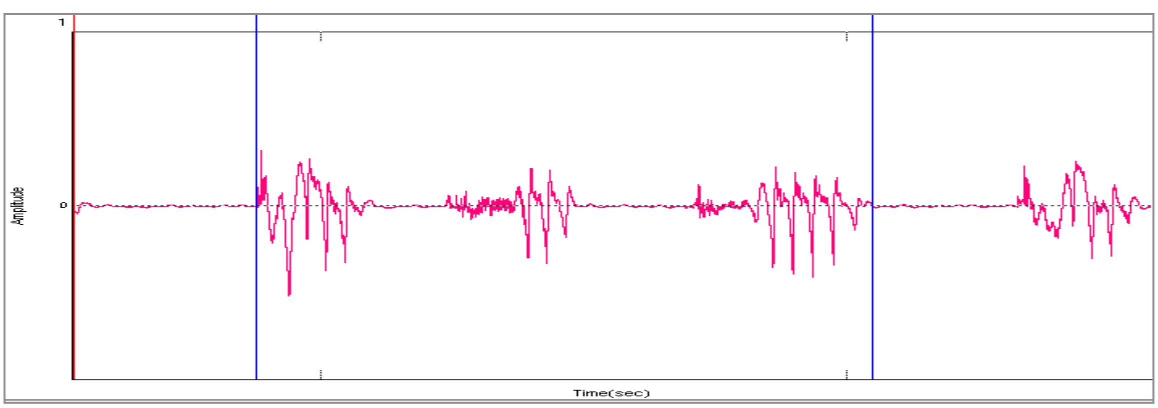

Illustration 3.3 Acoustic analysis showing blue cursors at the onset of /puh/ and offset /kuh/ of a /puhtuhkuh/ tri-syllable sequence (Hewitt, 2015).

For the AMR task, the investigator once again placed the cursor on the second onset of the /puh/ syllable and the other cursor on the final, 11th production, of the /puh/. A 0.3-second window expansion was also set to measure the onset and offset of the entire sequence. Cursors were then manually set at the onset and offset of each /puh/ syllable to obtain a syllable duration time without intersyllable gap durations. One to three /puh/ waveforms were analyzed at (see illustration 3.4), using a 0.5-second window expansion for the control group. The same procedure was used to analyze the waveforms for the other syllables: /tuh/ and /kuh/.

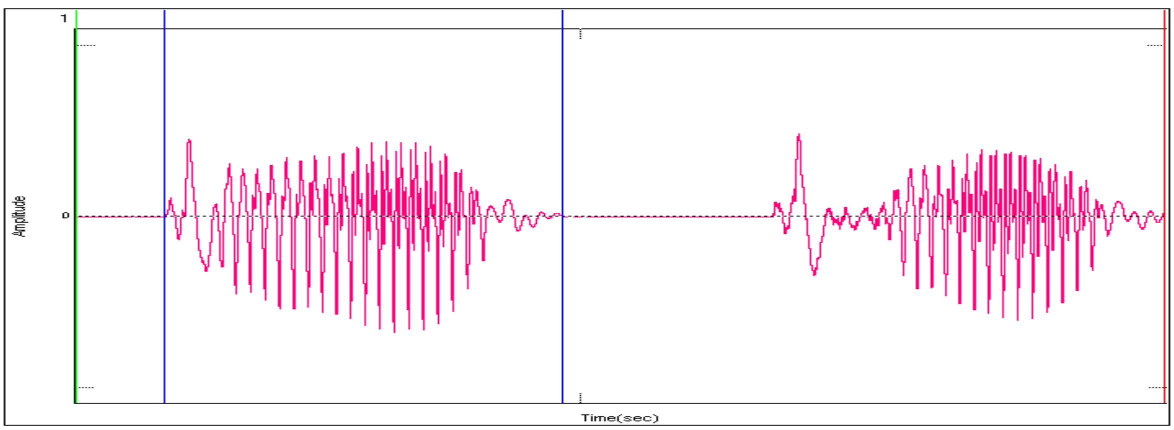

Illustration 3.4 Acoustic analysis showing blue cursors at the onset and offset of the /puh/ syllable (Hewitt, 2015).

For comparison between groups, mean syllable duration and total mean duration were calculated to include measurements with and without intersyllable gap durations. Furthermore, intersyllable gap durations were obtained for the AMR tasks to be compared between groups.

3.8.2 Speech rate and intelligibility analysis

In accordance with the standardization procedure for judging the SIT task, the examiner assigned a trained research assistant to transcribe the sentences, using audio playback, for each analysis, as the person judging the sentences cannot have foreknowledge of the content of the sentences (Yorkston, Beukelman, and Hakel, 1996). After listening to the sentence, the judge (a

trained assistant) typed the words that were heard into the window. Once the judge checked for typing and spelling errors at the end of each sentence, the judge advanced to the next sentence. The SIT software automatically scored the intelligibility of the transcribed sentences. The trained assistant measured the time duration by clicking the "start timer" button to begin timing at the first word of the sentence, and "stop timer" at the completion of the last word of the sentence. Audio playback was used simultaneously with the timer provided in the SIT software. Upon completion of this transcription and timing process, the SIT software provided the intelligibility percentage, speech rates (IWPM and WPM), and CER for each participant.

The SIT software provided a detailed report that also included the actual sentences produced by each participant. This report was then used to calculate the syllables per minute. The examiner manually counted the number of syllables in each sentence, added the syllables together, divided that number by the total composite duration time (provided in the SIT report), and then multiplied it by 60 to obtain syllables per minute (SPM).

3.8.3 Limb task analysis

For the analysis of the finger repetition task, the same analysis procedure used in Hewitt (2015) was also implemented. The video analysis was completed via QuickTime player, version 10.4. Once the desired video was selected, the examiner selected the *edit* option and then *trim*. This enabled the examiner to view an enlarged screen of the video, while also providing small trimmings of the same video at the bottom with a cursor and time in seconds. As the examiner manually moved the cursor at the bottom along the video trimmings, the finger repetitions were viewed in the enlarged screen in slow motion, enabling the examiner to accurately calculate the duration time for the finger repetitions using time provided by the program. Out of twelve of the finger repetition sequences, only ten were measured to ensure that each participant was timed

accurately. The initial time began as contact was made between the pointer finger and thumb of the second finger sequence. The timing ended with the final contact of the ring finger and thumb of the 11th finger sequence.

For the analysis for movement execution initiation time task, time was recorded in real-time as the stopwatch provided the actual time it took the participant to push the start and stop button. Each participant completed three trials for this task, which were then averaged to provide one total movement execution initiation time.

3.9 Reliability

To ensure the reliability of procedures conducted in this study, the same standardized instructions used in the Hewitt (2015) study were utilized in this current study and administered before each motor speech and motor limb task to warrant consistency. In addition, an Intraclass Correlation Coefficient (ICC), one-way random, was used to index all reliability measures.

Twenty-five percent of the DDK tasks in the SRC and the control group were randomly selected to be re-measured. Table 3.4 shows the results of an ICC, one-way random, intra-rater agreement for both groups.

Table 3.4 Reliability measures for DDK tasks between both groups.

DDK Tasks	SRC	CONTROL
SMR W/GAP	0.994	0.931
SMR W/O GAP	0.903	0.998
PUH W/GAP	1.00	0.995
PUHW/O GAP	0.927	1.00
TUH W/GAP	0.988	1.00
TUHW/O GAP	0.995	0.999
KUH W/GAP	0.999	0.999
KUH W/O GAP	0.999	0.997

Eighty percent of the finger repetition tasks, for the control group and SRC group, were randomly selected to be re-calculated. The finger repetition tasks were also re-analyzed using the

trim option in the QuickTime player, version 10.4. An ICC showed an inter-rater agreement of 0.999 for the control group and 0.997 for the SRC group between raters.

A trained research assistant transcribed all of the SIT samples to determine consistency in IWPM. In addition, a second trained research assistant transcribed 25% of the samples for both the SRC and control group to ensure reliability. An ICC showed an inter-rater agreement of 0.992 for the control group and 0.991 for the SRC group between raters.

3.10 Data analysis

SPSS version 20.0 software was utilized for statistical analysis in this study. A Shapiro Wilk-test of normality was used to determine if the groups were normally distributed. The test determined the SRC group did not have normal distribution for certain tasks. Independent *t*-tests ($\alpha = 0.05$), one-way ANOVA ($\alpha = 0.05$) and Spearman's *rho* correlation coefficient were utilized to determine if there were significant differences or correlations on a variety of parameters. A series of independent *t*-tests were used to examine the possible differences of mean syllable duration times and total mean duration for the motor limb tasks between the SRC group and the control group. A one-way ANOVA was used to examine differences in speech rate tasks between groups. However, the Mann-Whitney U, a non-parametric test, was calculated to verify parametric test results for all tasks due to the lack of a normal distribution.

A Spearman correlation coefficient was used to examine the relationship between DDK tasks and motor limb duration times. The similarities between sequential movements of the finger repetition task and the SMR task warrant a correlational analysis to examine the relationship with an increased sample size in both groups (Hewitt, 2015). The Spearman correlation coefficient was also used to examine the relationship between ImPACT composite scores, DDK mean syllable duration times, speech rate, and total mean duration for the motor

limb tasks. The ImPACT test modules yield scores that are indicative of different cognitive functions. Because each task differs in cognitive demands, it was of interest to examine if there was any correlation in regards to functional deficits.

Chapter IV: Results

This study was designed to systematically replicate and extend previous research by examining the effects of concussion on motor speech and motor limb movements in individuals with and without a sport-related concussion. This chapter describes the combined findings of Dolan's (2013) and Hewitt's (2015) SRC and control group, and with the current SRC group and normal data.

4.1 Oral diadochokinesis: Mean Syllable Duration

The first research question aimed to examine the differences in DDK mean syllable duration between the SRC group and the control group. Results yielded slower DDK mean syllable duration in the SRC group in comparison to the control group. Independent-samples *t*-test revealed a statistically significant difference in the following DDK mean syllable duration across groups: SMRs [$t(34) = -3.360$, $p = .002$], AMR /tuh/ [$t(34) = -2.635$, $p=.013$], and AMR /kuh/ [$t(34) = -3.007$, $p=.005$]. However, the independent *t*-test did not reveal a statistically significant difference for AMR /puh/.

The results for mean syllable duration times, in milliseconds, are noted as follows: SMRs- 156 milliseconds ± 44.3 in comparison to 115 milliseconds ± 28.45 for the control group; AMR /puh/- 158 milliseconds ± 47.9 exhibited for the SRC group in comparison to 132 milliseconds ± 34.42 for the control group; AMR /tuh/- 186 milliseconds ± 51.25 for the SRC group in comparison to 145 milliseconds ± 41 for the control group; AMR /kuh/- 195 milliseconds ± 52.42 in the SRC group in comparison to 150 milliseconds ± 38.57 for the control group. Figure 4.1 displays all DDK mean syllable duration times.

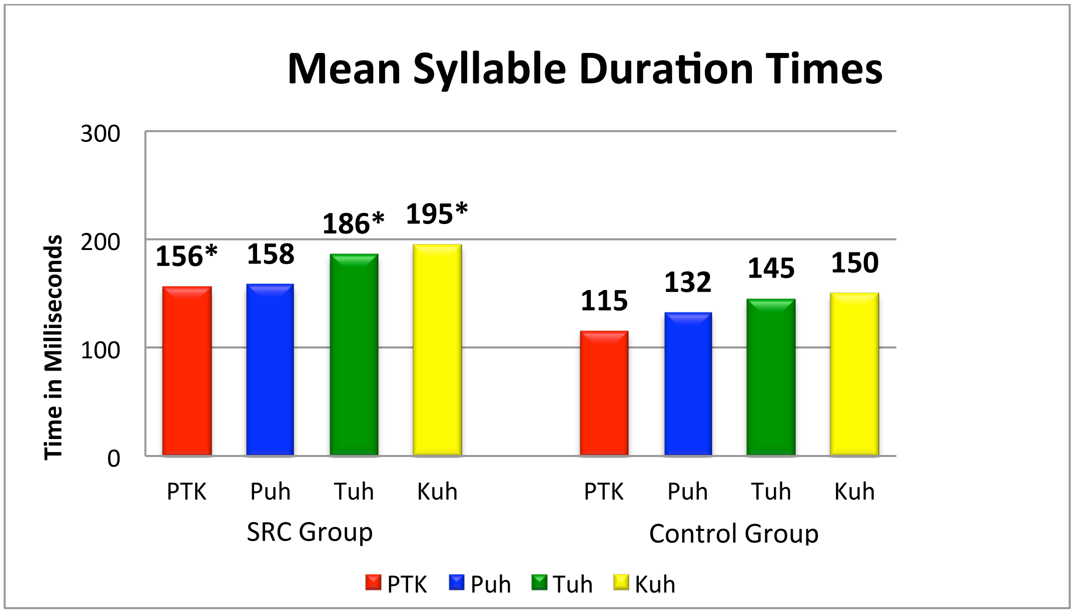

Figure 4.1 DDK mean syllable duration across groups. Group comparisons for SMRs include data from Dolan's (2013), Hewitt's (2015) and Phan's (2016) data. Group comparisons for AMRs include Hewitt (2015) and Phan (2016) data only.
Asterisk shows significance at the .05 level or less.

4.2 DDK mean total duration

In this analysis, independent-samples *t*-tests demonstrated an overall slower mean duration across all DDK tasks, with and without intersyllable gap durations, between the SRC and the control group. However, an independent-samples *t*-test did not reveal a statistically significant difference, between groups, for total mean duration for SMRs, with gap durations, [t(42) = -.971, p = .337]. The total mean duration for SMRs in the SRC group was 5.27 seconds ± 0.87 while the total mean duration for SMRs in the control group was 4.95 seconds ± 1.28.

An independent-samples *t*-test used to analyze AMRs, with intersyllable gap durations, revealed a statistically significant difference for only /tuh/. The following are the results for all three syllables between groups: /puh/ [t(34) = -.467, p = .644], /tuh/ [t(34) = -2.315, p = .027], and /kuh/ [t(34) = -1.594, p = .120]. The results for the overall mean duration times, with intersyllable gap durations, are noted as follows: /puh/ syllable was 2.16 seconds ± 0.48 for the

SRC group in comparison to 2.05 seconds ± 0.82 for the control group. The overall mean duration of the /tuh/ syllable was 2.37 seconds ± 0.62 for the SRC group in comparison to 1.94 seconds ± 0.49 for the control group. The overall mean duration of the /kuh/ syllable was 2.49 seconds ± 0.62 for the SRC group in comparison to 2.14 seconds ± 0.63 for the control group.

In addition, a statistically significant difference was not found for the SMRs, without gap durations, [$t(42) = -1.775$, $p = .083$], between groups. The overall mean duration for SMRs for the SRC group was 4.74 seconds ± 0.77, and the overall mean duration for the SMRs for the control group was 4.19 seconds ± 1.20.

In analyzing the AMRs, without intersyllable gap durations, an independent-samples *t*-test revealed a statistically significant difference of only /tuh/ and /kuh/: /puh/ [$t(34) = -1.889$, $p = .067$], /tuh/ [$t(34) = -2.635$, $p = .013$], and /kuh/ [$t(34) = -3.007$, $p = .005$], between groups. The overall mean duration, without intersyllable gap durations, of the /puh/ syllable was 1.58 seconds ± 0.47 for the SRC group in comparison to 1.32 seconds ± 0.34 for the control group. The overall mean duration of the /tuh/ syllable was 1.86 seconds ± 0.51 for the SRC group in comparison to 1.45 seconds ± 0.41 for the control group. The overall mean duration of the /kuh/ syllable was 1.95 seconds ± 0.52 for the SRC group in comparison to 1.50 seconds ± 0.38 for the control group.

The results suggest that the SRC group exhibited slower total mean duration, for the SMRs and AMRs, with and without intersyllable gap durations, compared to the control group. However, statistically significant differences were only found with AMR /tuh/, with intersyllable gap durations, and AMR /tuh/ and /kuh/, without intersyllable gap durations, between groups. Figure 4.2 summarizes the SMR total mean duration times, while Figure 4.3 summarizes AMR results between groups.

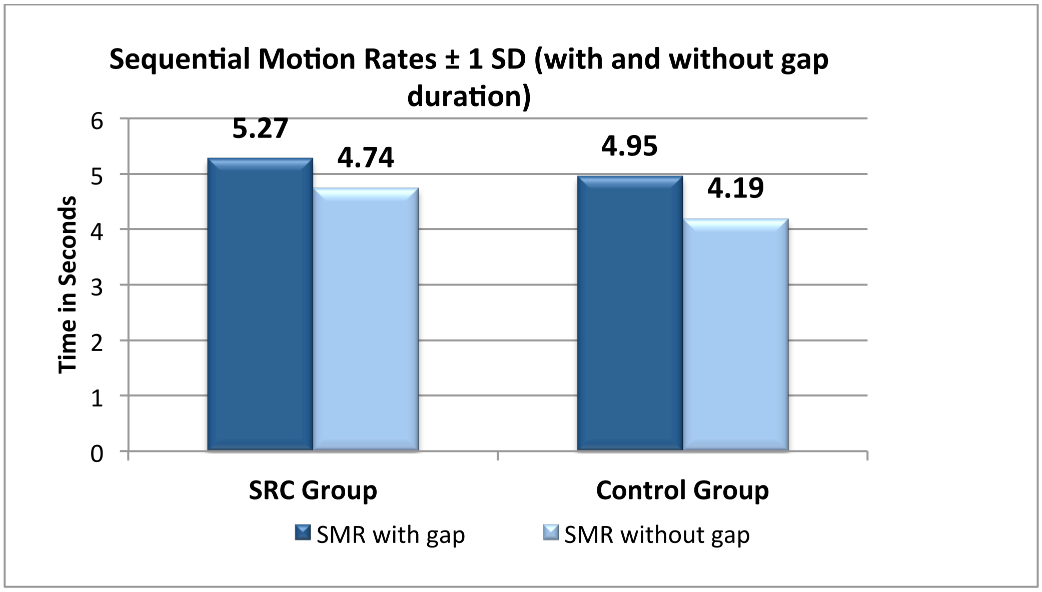

Figure 4.2 SMR total mean duration (with and without gap durations) across groups. Group comparisons include Dolan (2013), Hewitt (2015), and Phan (2016) data.

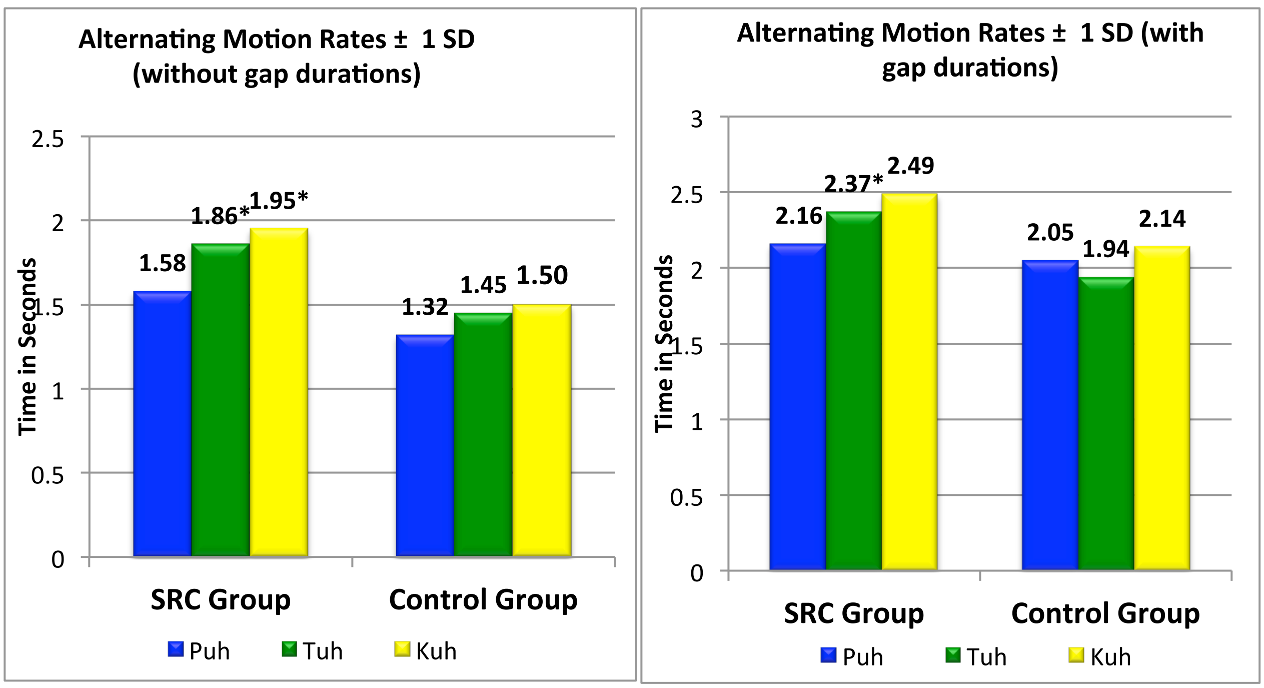

Figure 4.3 AMR total mean duration, with and without intersyllable gap durations, across groups. Group comparisons include Hewitt (2015) and Phan (2016) data.
Asterisk shows significance at the .05 level or less.

4.3 DDK intersyllable gap durations

An independent-samples *t*-test was used to analyze DDK intersyllable gap durations, in milliseconds, between the SRC group and the control group. The results did not reveal a

statistically significant difference for SMRs or AMRs for this task between groups. The following are the results for DDK mean intersyllable gap durations SMR [t(34) = -.054, p = .957, AMR:/puh/ [t(34) = -.045, p = .964], AMR: /tuh/ [t(34) = .245, p = .808], and AMR: /kuh/ [t(34) = -.436, p = .665]. The results for SMR mean for intersyllable gap duration was 84.21 milliseconds ± 29.23 for the SRC group in comparison to 83.72 milliseconds ± 24.55 for the control group. The overall mean for intersyllable gap duration AMR /puh/ intersyllable gap duration was 64.64 milliseconds ± 11.8 for the SRC group in comparison to 64.40 milliseconds ± 17.01 for the control group. The overall mean for intersyllable gap duration AMR /tuh/ intersyllable gap duration was 59.21 milliseconds ± 17.5 for the SRC group in comparison to 57.22 milliseconds ± 27.3 for the control group. The overall mean for intersyllable gap duration AMR /kuh/ intersyllable gap duration was 59.92 milliseconds ± 18.5 for the SRC group in comparison to 57.59 milliseconds ± 13.5 for the control group. Figure 4.4 displays a summary of mean intersyllable gap duration times.

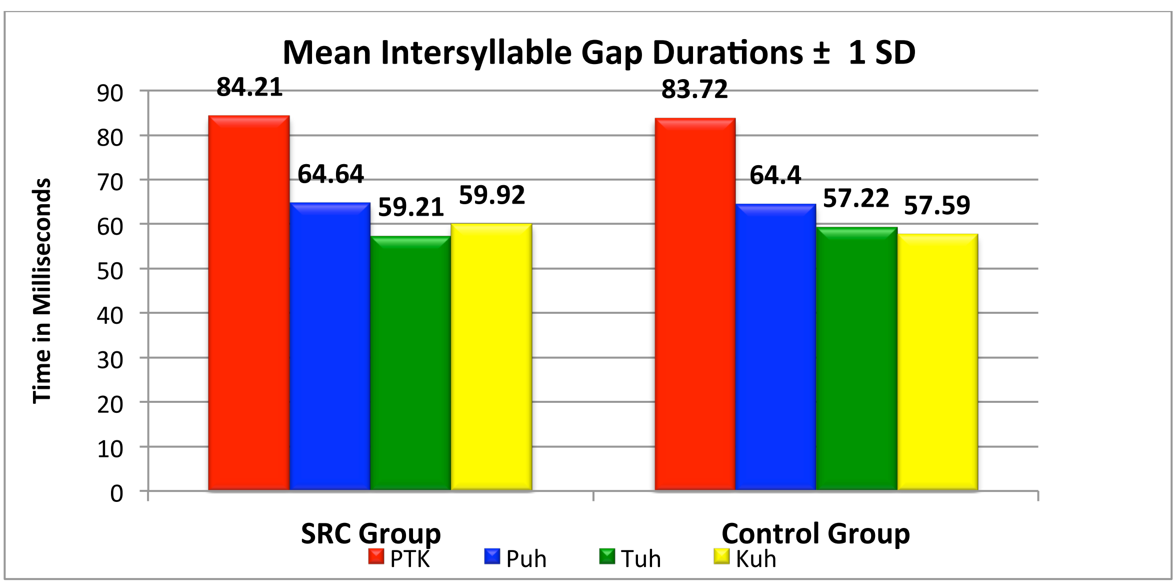

Figure 4.4 Mean intersyllable gap duration across groups; Hewitt (2015) and Phan (2016) data only.

4.4 Speech rates between groups

The second research question aimed to investigate the speech rate between the SRC group in comparison to the control group. A one-way ANOVA did not reveal statistically significant differences between the groups for WPM, IWPM, syllables per minute (SPM), or CER.

For total words per minute (WPM), there was no statistically significant difference [$F(1,34) = .067$, $p = .797$] between groups. The total mean duration in WPM for the SRC group was 198.53 words per minute ± 25.74 in comparison to 196.06 words per minute ± 29.09 for the control group.

There was no statistically significant difference for intelligible words per minute (IWPM), [$F(1,34) = 0.10$, $p = .920$] between groups. The total mean duration in IWPM for the SRC group was 196.27 intelligible words per minute ± 27.30 in comparison to195.30 intelligible words per minute ± 28.53 for the control group.

For SPM, there was no statistically significant difference [$F(1,34) = .096$, $p = .759$] between groups. The total mean duration for SPM for the SRC group was 266.05 syllables per minute ± 30.45 in comparison to 269.74 syllables per minute ± 37.36 for the control group. Figure 4.5 provides a summary for speech rates across groups.

For Communication Efficiency Ratio (CER) there was no statistically significant difference between groups [$F(1,34) = .011$, $p = .918$] between groups. The total mean duration in CER for the SRC group was 1.03 ± .138 in comparison to 1.02 ± .150 for the control group. Figure 4.6 displays the CER results.

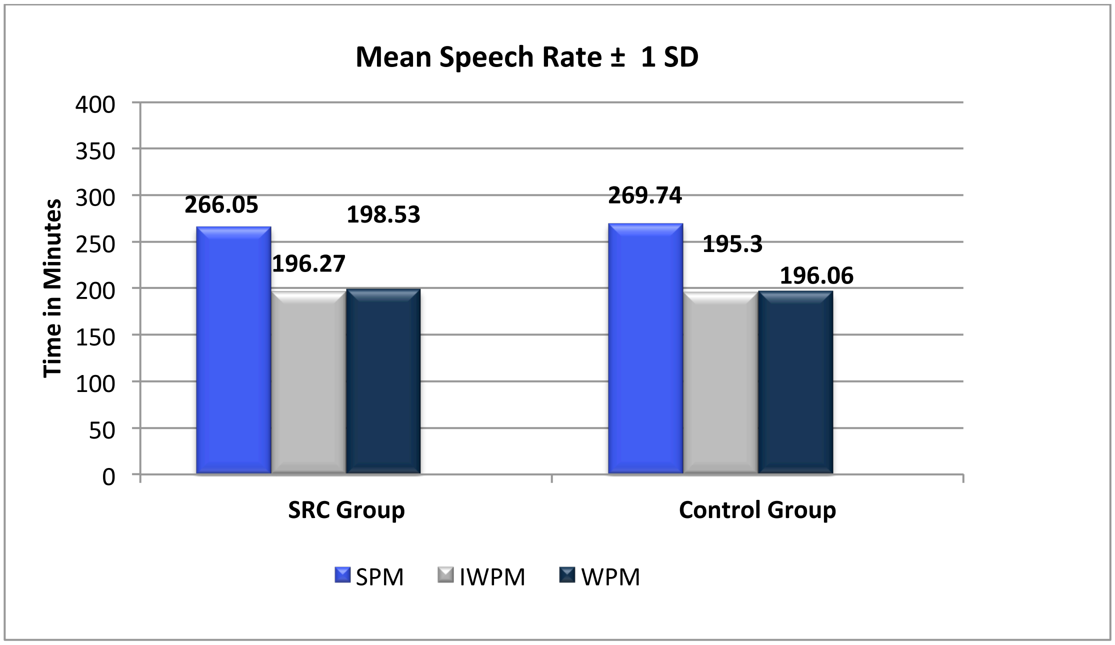

Figure 4.5 Speech rate results across groups. Group comparisons include Hewitt (2015) and Phan (2016) data only.

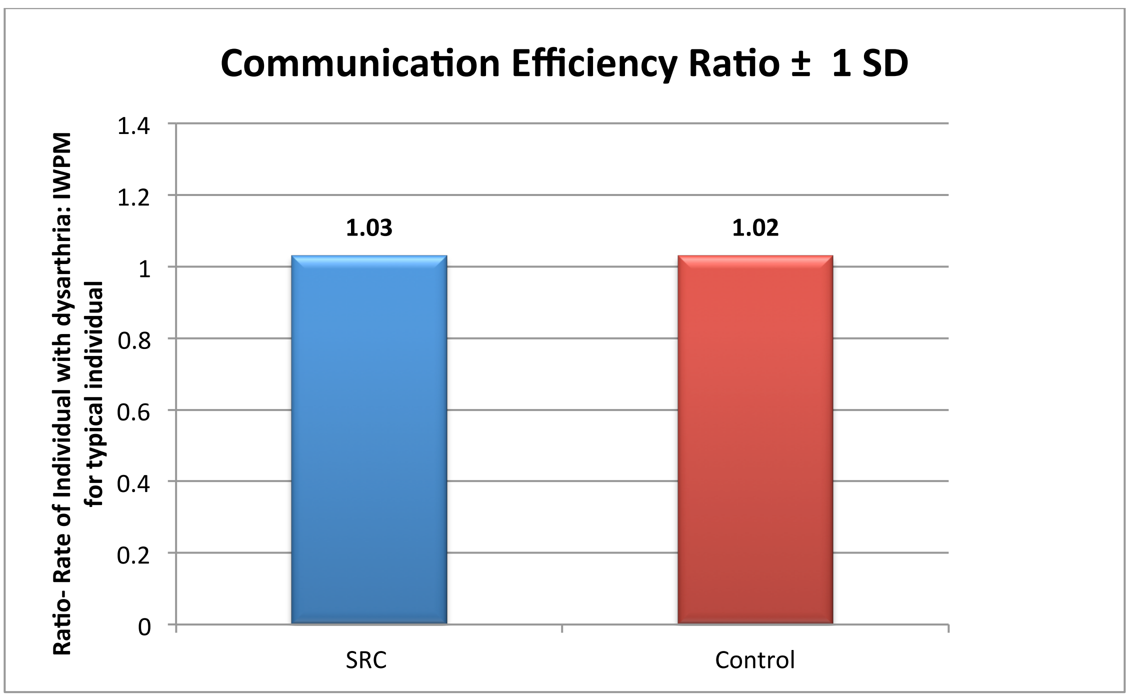

Figure 4.6 Summary of communication efficiency ratio across groups. Group comparisons include Hewitt (2015) and Phan (2016) data.

4.5 Correlation between DDK mean syllable duration times and speech rate

The third research question aimed to investigate the level of relationship between the DDK mean syllable duration in milliseconds, with gap durations, and the speech rate tasks between groups, in which a Spearman rho correlation coefficient was used to answer this question. The test revealed no statistically significant differences and a very weak to moderate relationship between DDK mean syllable duration, with gap durations, and speech rate tasks. Table 4.1 provides the correlation results for DDK tasks and speech rate.

Table 4.1 Spearman Correlation: DDK mean syllable duration (w/gaps) and speech rate across groups

Tasks	SRC Group	Control Group
SMR and IWPM	[*r* (14) = -.187, p = .522]	[*r* (22) = .043, p = .850]
SMR and SPM	[*r* (14) = -.114, p = .697]	[*r* (22) = .069, p = .759]
AMR: /puh/ and IWPM	[*r* (14) = .451, p = .106]	[*r* (22) = -.142 p = .529]
AMR :/puh/ and SPM	[*r* (14) = .402, p = .154]	[*r* (22) = -.173, p = .442]
AMR: /tuh/ and IWPM	[*r* (14) = .196, p = .502]	[*r* (22) = -.186, p = .406]
AMR : /tuh/ and SPM	[*r* (14) = .141, p = .631]	[*r* (22) = -.189, p = .400]
AMR: /kuh/ and IWPM	[*r* (14) = .415, p = .140]	[*r* (22) = -.249, p = .264]
AMR : /kuh/ and SPM	[*r* (14) = .279, p = .334]	[*r* (22) = -.242, p = .278]

Note: Group comparisons for SMRs include data from Dolan's (2013), Hewitt's (2015) and Phan's (2016) data. Group comparisons for AMRs and speech rate tasks include Hewitt (2015) and Phan (2016) data only.

4.6 Speech intelligibility

For speech intelligibility, an independent samples *t*-test was utilized to determine any statistically significant differences for intelligibility across groups. However, no statistically significant differences were found for this task [t(34) = .599, p =. 553] between the groups. The mean intelligibility is noted as follows: 98.22 ± 1.61 for the SRC group in comparison to 98.53 ± 1.45 for the control group.

4.7 Motor limb tasks between groups

For the fourth research question, an independent samples *t*-test was used to investigate the differences in motor limb tasks between groups. This test revealed that the SRC group had

overall slower duration time for limb movements as compared to the control group. However, only movement execution initiation time was found to have a statistically significant difference between the groups.

There was no significant difference found for the finger repetition task [t(42) = -.773, p = .444] between groups. The total mean duration for this task was 8.02 seconds ± 1.57 for the SRC group in comparison to 7.57 seconds ± 2.23 for the control group. Figure 4.7 provides a summary of finger repetition results.

The independent samples *t*-test found a statistical significant difference for the movement execution initiation task [t(42) = -2.090, p = .043] between groups. The total mean duration for this task was 165.45 milliseconds ± 127.41 for the SRC group in comparison to 106.04 milliseconds ± 39.33 for the control group. Figure 4.8 provides the results for the mean movement execution initiation time task.

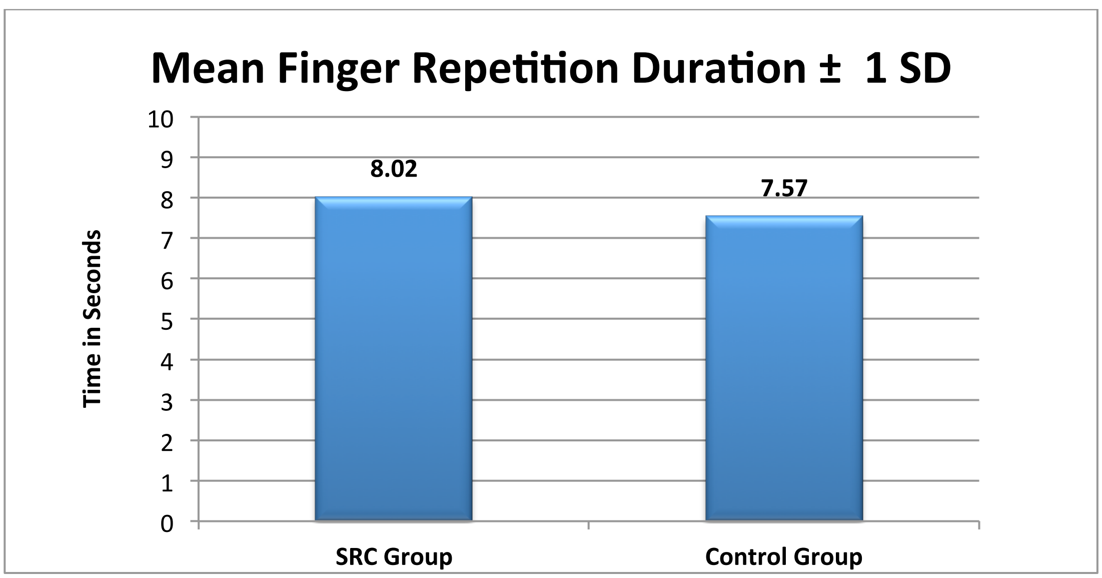

Figure 4.7 Finger repetition duration in seconds across groups. Group comparisons include Dolan (2013), Hewitt (2015), and Phan (2016) data.

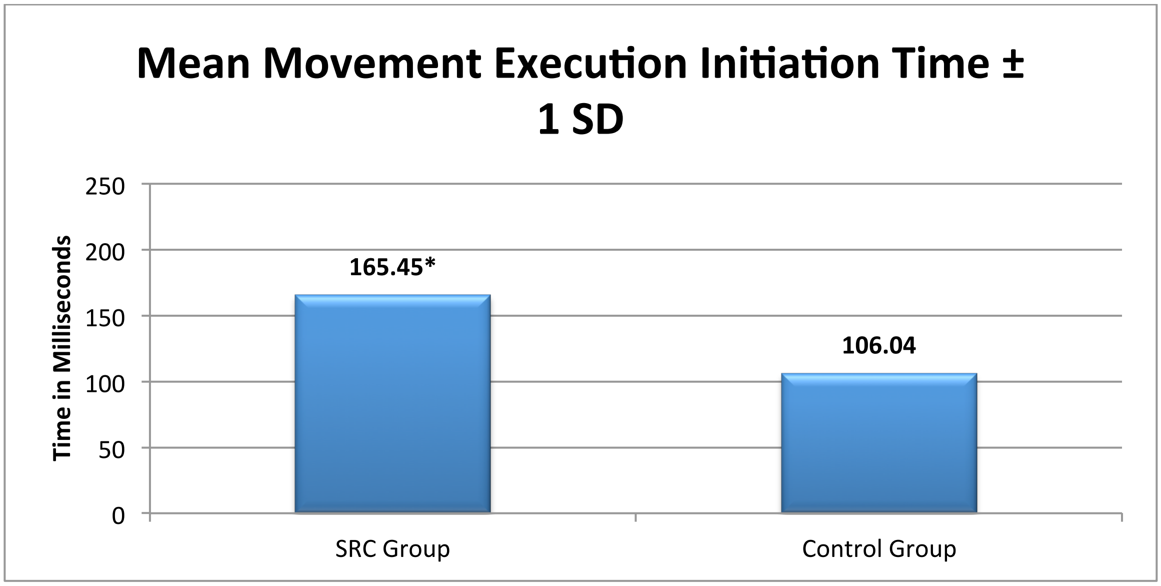

Figure 4.8 Mean movement execution initiation time task in milliseconds across groups. Group comparisons include Dolan (2013), Hewitt (2015), and Phan (2016) data.
Asterisk shows significance at the .05 level or less.

4.8 Correlation between DDK and motor limb tasks

The fifth research question aimed to investigate the correlation between the DDK total mean duration times, without intersyllable gap durations, and the motor limb tasks between groups. For this analysis, a Spearman *rho* correlation coefficient was utilized to determine if there was a relationship between DDK and motor limb tasks between groups. This test found that there was a weak relationship that was not statistically significant between DDK tasks and motor limb tasks. Table 4.2 provides the correlation results for DDKs and motor limb tasks.

Table 4.2 Spearman correlation coefficient: DDK mean total duration and motor limb tasks

Tasks	SRC Group	Control Group
SMRs and Finger Repetition	[*r* (22) = .150, p = .506]	[*r* (22) = -.167, p = .457]
SMRs and Mvmt. Ex. Initiation	[*r* (22) = .239, p = .283]	[*r* (22) = -.087, p = .699]
AMR: /puh/ and Finger Repetition	[*r* (14) = .051, p = .864]	[*r* (22) = .096, p = .672]
AMR: /puh/ and Mvmt. Ex. Initiation	[*r* (14) = -.490, p = .076]	[*r* (22) = -.143, p = .525]
AMR: /tuh/ and Finger Repetition	[*r* (14) = .176, p = .547]	[*r* (22) = -.040, p = .859]
AMR: /tuh/ and Mvmt. Ex. Initiation	[*r* (14) = -.347, p = .225]	[*r* (22) = .028, p = .900]
AMR: /kuh/ and Finger Repetition	[*r* (14) = .288, p = .318]	[*r* (22) = -.183, p = .220]

AMR: /kuh/ and Mvmt. Ex. Initiation	[*r* (14)= -.351, p = .219]	[*r* (22)= .079, p = .727]

Note: Group comparisons for SMRs and limb tasks include data from Dolan's (2013), Hewitt's (2015) and Phan's (2016) data only. Group comparisons for AMRs and limb tasks include Hewitt (2015) and Phan (2016) data only.

4.9 Correlation between ImPACT composite scores and DDK tasks

For the sixth question, a Spearman *rho* correlation coefficient was used to find the correlation between ImPACT composite scores and DDK total mean duration times, without intersyllable gap durations. A statistically significant moderate positive relationship was found between SMR and the reaction time composite score, in the SRC group, [r (14)= .441, p = .040]. Furthermore, a moderate positive relationship was also found between AMR /puh/ and the McVisual composite score, in the control group, [r (22) = .467, p = .028]. Table 4.3 provides the correlation results for DDKs and ImPACT composite scores.

Table 4.3 Spearman Correlation: ImPACT composite scores and DDKs

Tasks	SRC Group	Control Group
SMR and McVerbal	[r (14) = -.350, p = .110]	[r (22) = -.024, p = .917]
SMR and McVisual	[r (14) = -.257, p = .249]	[r (22) = .117, p = .605]
SMR and VMSC	[r (14) = -.335, p = .128]	[r (22) = .233, p = .297]
SMR and Reaction Time	[r (14) = .441, p = .040]*	[r (22) = .044, p = .844]
AMR: /puh/ and McVerbal	[r (14) = .255, p = .439]	[r (22) = -.273, p = .219]
AMR: /puh/ and McVisual	[r (14) = -.410, p = .146]	[r (22) = .467, p = .028]*
AMR: /puh/ and VMSC	[r (14) = .270, p = .350]	[r (22) = .231, p = .302]
AMR: /puh/ and Reaction Time	[r (14) = -.020, p = .946]	[r (22) = -.022, p = .923]
AMR: /tuh/ and McVerbal	[r (14) = -.018, p = .952]	[r (22) = -.050, p = .826]
AMR: /tuh/ and McVisual	[r (14) = -.417, p = .138]	[r (22) = .330, p = .134]
AMR: /tuh/ and VMSC	[r (14) = .117, p = .691]	[r (22) = .284, p = .200]
AMR: /tuh/ and Reaction Time	[r (14) = -.017, p = .955]	[r (22) = .113, p = .617]
AMR: /kuh/ and McVerbal	[r (14) = -.110, p = .707]	[r (22) = -.115, p = .611]
AMR: /kuh/ and McVisual	[r (14) = .434, p = .121]	[r (22) = .215, p = .336]
AMR: /kuh/ and VMSC	[r (14) = .336, p = .240]	[r (22) = .322, p = .143]
AMR: /kuh/ and Reaction Time	[r (14) = -.115, p = .696]	[r (22) = -.081, p = .721]

Note: Group comparisons for SMRs and limb tasks include data from Dolan's (2013), Hewitt's (2015) and Phan's (2016) data only. Group comparisons for AMRs and limb tasks include Hewitt (2015) and Phan (2016) data only. McVerbal-Verbal memory; McVisual- Visual memory; VMSC- Visual Motor Speed. Asterisk shows significance at the .05 level or less.

4.10 Correlation between ImPACT composite scores and speech rate

The seventh research question aimed to determine if there was a correlation between ImPACT composite scores and speech rate tasks. To answer this question the Spearman *rho* correlation coefficient was utilized, which determined a statistically significant moderate positive relationship between the McVerbal composite score and IWPM, as well as a statistically significant moderate positive relationship between the McVerbal composite score and SPM. Lastly, a statistically significant strong relationship was found between the McVisual composite score and IWPM. Table 4.4 provides the correlation results for ImPACT composite scores and speech rate tasks.

Table 4.4 Spearman correlation coefficient: ImPACT composite scores and Speech Rate

Tasks	SRC Group	Control Group
McVerbal and IWPM	[r (14) = .406, p = .150]	[r (22) = .432, p = .044]*
McVerbal and SPM	[r (14) = .123, p = .674]	[r (22) = .466, p = .029] *
McVisual and IWPM	[r (14) = .643, p = .013]*	[r (22) = -.037, p = .871]
McVisual and SPM	[r (14) = .297, p = .302]	[r (22) = .012, p = .956]
VMSC and IWPM	[r (14) = .455, p = .102]	[r (22) = .187, p = .405]
VMSC and SPM	[r (14) = .099, p = .737]	[r (22) = .188, p = .402]
Reaction Time and IWPM	[r (14) = -.346, p = .255]	[r (22) = .027, p = .904]
Reaction Time and SPM	[r (14)= -.121, p = .680]	[r (22) = -.015, p = .948]

Note: Group comparisons for ImPACT composite scores include data from Dolan's (2013), Hewitt's (2015) and Phan's (2016) data only. Group comparisons for speech rate include Hewitt (2015) and Phan (2016) data only. McVerbal-Verbal memory; McVisual- Visual memory; VMSC- Visual Motor Speed
Asterisk shows significant correlation at the 0.5 level.

4.11 Correlation between ImPACT composite scores and motor limb tasks

For the eighth research question, a Spearman *rho* correlation coefficient was utilized to determine if there was a relationship between ImPACT composite scores and motor limb tasks between groups. The Spearman *rho* correlation revealed a range from very weak to weak

relationship between ImPACT composite scores and motor limb tasks. There were no statistically significant differences found for these tasks between groups. Table 4.5 displays the correlation results for ImPACT composite scores and motor limb tasks.

Table 4.5 Spearman correlation coefficient: ImPACT composite scores and total mean duration for motor limb tasks

Tasks	SRC Group	Control Group
Finger Repetition and McVerbal	[r (22) = -.296, p = .181]	[r (22) = -.357, p = .103]
Finger Repetition and McVisual	[r (22) = -.327, p = .137]	[r (22) = -.166, p = .461]
Finger Repetition and VMSC	[r (22) = -.069, p = .759]	[r (22) = -.044, p = .846]
Finger Repetition and Reaction time	[r (22) = .184, p = .412]	[r (22) = .151, p = .502]
Mvmt. Ex. Initiation and McVerbal	[r (22) = -.021, p = .925]	[r (22) = -.067, p = .767]
Mvmt. Ex. Initiation and McVisual	[r (22) = -.208, p = .354]	[r (22) = -.168, p = .454]
Mvmt. Ex. Initiation and VMSC	[r (22) = .130, p = .565]	[r (22) = -.051, p = .821]
Mvmt. Ex. Initiation and Reaction time	[r (22) = .184, p = .413]	[r (22) = .041, p = .856]

Note: Group comparisons for limb tasks and ImPACT composite scores include Dolan (2013), Hewitt (2015), and Phan (2016) data.

4.12 Non- parametric analysis

A Mann-Whitney-U was computed for all tasks across both groups to verify the parametric test results. Table 4.6 displays the results.

Table 4.6 Mann-Whitney-U results for all tasks across both groups.

Tasks	Asymp.Sig (2-tailed)
/puh,tuh,kuh/ tri-syllable total mean duration	p = 0.001*
/puh,tuh,kuh/ with gap duration	p = 0.001*
/puh,tuh,kuh/ without gap duration	p = 0.001*
/puh/ mean syllable duration time	p = 0.001*
/puh/ total mean with intersyllable gap duration	p = 0.033

/puh/ total mean without intersyllable gap duration	p = 0.001*
/tuh/ mean syllable duration	p = 0.005*
/tuh/ total mean with intersyllable gap duration	p = 0.005*
/tuh/ total mean without intersyllable gap duration	p = 0.005*
/kuh/ mean syllable duration	p = 0.005*
/kuh/ with intersyllable gap duration	p = 0.005*
/kuh/ without intersyllable gap duration	p = 0.005*
Finger Repetition task	p = 0.895
Movement Execution Initiation Time task	p = 0.006*
WPM	p = 0.422
IWPM	p = 0.146
SPM	p = 0.001*
Intelligibility	p = 0.116
CER	p = 0.218
McVerbal	p = 0.787
McVisual	p = 0.662
VMSC	p = 0.500
Reaction Time	p = 0.096

Results include Dolan (2013), Hewitt (2015), and Phan (2016) data combined only for the limb tasks and the SMRs tasks. Asterisk shows significance at the 0.5 or less level.

Table 4.6 Mean and standard deviation for control group for all tasks (N=101)

Dependent Variables	***Mean***	***SD***
Finger Repetition Task (sec)	8.23	2.39
Mvmt. Ex. Initiation Time (ms)	104.10	43.11
Intelligibility (%)	98.93	1.37
WPM	201.73	25.05
IWPM	213.42	111.31
SPM	278.34	36.77
/puh/ /tuh/ /kuh/ tri-syllable mean duration	1.03	.26
/puh/ /tuh/ /kuh/ with gap	4.60	1.08
/puh/ /tuh/ /kuh/ without gap	3.93	.99
/puh/ mean syllable duration	1.33	0.41
/puh/ total mean with intersyllable gap	1.92	0.58
/puh/ total mean w/o intersyllable gap duration	1.33	0.41
/tuh/ mean syllable duration	1.45	0.42
/tuh/ total mean w/ intersyllable gap duration	1.94	0.47
/tuh/ total mean w/o intersyllable gap duration	1.45	0.42

/kuh/ mean syllable duration	1.54	0.47
/kuh/ with intersyllable gap duration	2.03	0.56
/kuh/ without intersyllable gap duration	1.54	0.47

Note: Values represented in this table are based on *n*=101, ages 13-39, 38 males and 63 females. Within this group, 22.7% (23) of individuals played recreational sports. This data includes combined data from the Hewitt (2015) study control group.

Table 4.7 Summary of demographic for normative data (*n*=101)

Characteristics	Control Group
Age	23.65 (± 4.80)
Gender	38 Males, 63 Females
Recreational sport	22.7 (± .42)
Adolescents (13-17 yrs.)	38
Adults (18-39 yrs.)	63

Standard deviations are represented in parenthesis.

4.13 Overall results

Results for each participant are reported in the tables below. DDK total duration times, with and without intersyllable gap durations, are displayed in Tables 4.8 (SRC group) and Table. 4.10 (control group). DDK mean syllable duration times (without intersyllable gap durations), speech rate, finger repetition, and movement execution initiation times are displayed in Table 4.9 (SRC group) and Table 4.11 (control group).

Table 4.8 DDK total duration times, with and without intersyllable gap durations, for the SRC group

Participant	Study	SMR total duration time in sec	/puh/ total duration time in sec	/tuh/total duration time in sec	/kuh/total duration time in sec	SMR total duration w/o intersyllable gap durations in sec	/puh/ total duration w/o intersyllable gap durations in sec	/tuh/ total duration w/o intersyllable gap durations in sec	/kuh/ total duration w/o intersyllable gap durations in
201	Hewitt (2015)	5.79	1.75	2.05	2.08	4.80	1.10	1.42	1.48
202	Hewitt (2015)	5.11	2.13	2.5	2.45	4.39	1.46	1.93	1.91
203	Hewitt (2015)	5.92	1.90	1.81	1.98	5.14	1.18	1.26	1.49
204	Hewitt (2015)	6.14	2.36	4.06	3.96	5.74	1.87	3.10	2.92

205	Hewitt (2015)	6.24	2.10	2.18	2.88	5.45	1.59	1.80	2.48
206	Hewitt (2015)	4.37	2.37	2.25	2.14	3.83	1.69	1.90	1.71
207	Hewitt (2015)	6.44	1.77	1.97	2.04	5.34	1.16	1.56	1.64
208	Hewitt (2015)	4.32	2.06	2.37	2.28	3.73	1.40	1.80	1.69
209	Hewitt (2015)	5.02	2.35	2.46	2.43	4.35	1.81	2.06	1.99
210	Hewitt (2015)	6.84	1.79	1.94	1.98	6.16	1.36	1.51	1.63
211	Dolan (2013)	4.15	N/A	N/A	N/A	4.07	N/A	N/A	N/A
212	Dolan (2013)	4.53	N/A	N/A	N/A	4.43	N/A	N/A	N/A
213	Dolan (2013)	3.69	N/A	N/A	N/A	3.59	N/A	N/A	N/A
214	Dolan (2013)	5.63	N/A	N/A	N/A	5.52	N/A	N/A	N/A
215	Dolan (2013)	4.21	N/A	N/A	N/A	4.11	N/A	N/A	N/A
216	Dolan (2013)	5.95	N/A	N/A	N/A	5.82	N/A	N/A	N/A
217	Dolan (2013)	5.80	N/A	N/A	N/A	5.63	N/A	N/A	N/A
218	Dolan (2013)	4.70	N/A	N/A	N/A	4.57	N/A	N/A	N/A
219	Phan (2016)	4.69	2.34	2.22	2.63	3.60	1.73	1.71	1.94
220	Phan (2016)	5.36	1.96	2.15	2.26	4.79	1.39	1.76	1.86
221	Phan (2016)	4.39	1.78	1.90	2.05	4.32	1.43	1.46	1.54
222	Phan (2016)	6.27	3.63	3.40	3.71	4.91	3.03	2.79	3.14

Table 4.9 Mean syllable duration times, speech rate, and limb tasks for the SRC group

Participant	Study	SMR mean duration time for trisyllable in ms	/puh/ mean syllable duration time in ms	/tuh/ mean syllable duration time in ms	/kuh/ mean syllable duration time in ms	IWPM	WPM	SPM	F.R. in sec.	MEI in ms
201	Hewitt (2015)	480	110	142	148	157.21	158.65	219.23	7.16	124
202	Hewitt (2015)	439	146	193	191	197.54	203.08	267.69	7.50	120
203	Hewitt (2015)	514	118	126	149	175.61	178.86	232.52	9.93	260
204	Hewitt (2015)	574	187	310	292	147.91	153.49	234.42	9.57	200

205	Hewitt (2015)	545	159	180	248	219.27	219.27	277.08	8.03	110
206	Hewitt (2015)	383	169	190	171	216.49	226.8	301.03	6.65	50
207	Hewitt (2015)	534	116	156	164	188.48	190.21	271.47	7.62	130
208	Hewitt (2015)	373	140	180	169	188.37	191.86	261.62	7.69	110
209	Hewitt (2015)	435	181	206	199	195.27	195.27	260.95	7.45	90
210	Hewitt (2015)	616	136	151	163	184.75	193.55	267.44	8.45	60
211	Dolan (2013)	407	N/A	N/A	N/A	N/A	N/A	N/A	5.63	130
212	Dolan (2013)	443	N/A	N/A	N/A	N/A	N/A	N/A	13.02	670
213	Dolan (2013)	359	N/A	N/A	N/A	N/A	N/A	N/A	9.02	170
214	Dolan (2013)	552	N/A	N/A	N/A	N/A	N/A	N/A	6.94	150
215	Dolan (2013)	411	N/A	N/A	N/A	N/A	N/A	N/A	7.78	130
216	Dolan (2013)	582	N/A	N/A	N/A	N/A	N/A	N/A	6.13	170
217	Dolan (2013)	563	N/A	N/A	N/A	N/A	N/A	N/A	7.25	160
218	Dolan (2013)	457	N/A	N/A	N/A	N/A	N/A	N/A	8.40	270
219	Phan (2016)	360	173	171	194	254.13	254.13	338.82	7.29	80
220	Phan (2016)	479	139	176	186	204.97	204.97	238.50	9.09	140
221	Phan (2016)	432	143	146	154	205.61	205.61	280.37	6.60	120
222	Phan (2016)	491	303	279	314	207.55	203.77	273.58	9.34	80

Table 4.10 DDK total duration times, with and without intersyllable gap durations, for the control group

Participant	**Study**	**SMR total duration time in sec**	**/puh/ total duration time in sec**	**/tuh/ total duration time in sec**	**/kuh/total duration time in sec**	**SMR total duration w/o intersyllable gap durations in sec**	**/puh/ total duration w/o intersyllable gap durations in sec**	**/tuh/ total duration w/o intersyllable gap durations in sec**	**/kuh/ total duration w/o intersyllable gap durations in sec**

101	Phan (2016)	4.94	1.85	1.90	1.67	4.40	1.36	1.57	1.44
102	Hewitt (2015)	4.03	1.61	1.41	1.70	3.28	1.05	.99	1.14
103	Phan (2016)	4.69	2.49	2.40	2.87	3.98	1.63	1.71	1.58
104	Hewitt (2015)	4.13	1.44	1.51	1.48	3.28	1.15	1.08	1.23
105	Hewitt (2015)	4.80	1.65	1.69	2.06	4.05	1.01	1.36	1.34
106	Phan (2016)	5.18	1.97	2.51	2.56	3.94	1.36	1.91	1.83
107	Phan (2016)	4.86	2.23	2.06	1.71	3.94	1.63	1.56	1.55
108	Hewitt (2015)	4.01	1.65	1.87	2.50	3.36	1.17	1.40	1.30
109	Hewitt (2015)	3.25	1.48	1.52	1.91	2.98	1.02	1.12	1.30
110	Hewitt (2015)	3.80	1.16	1.12	1.91	3.15	.82	.79	.92
111	Hewitt (2015)	4.14	1.56	1.54	1.69	3.44	1.10	1.07	1.12
112	Hewitt (2015)	4.27	1.49	1.43	1.23	3.46	1.03	.87	1.14
113	Hewitt (2015)	5.76	2.65	3.08	2.32	5.18	1.99	2.38	2.46
114	Phan (2016)	5.01	2.42	2.42	2.33	4.36	1.77	1.83	1.80
115	Hewitt (2015)	4.42	1.85	1.47	2.20	3.50	1.16	1.08	1.15
116	Phan (2016)	6.62	2.75	2.57	3.96	5.41	1.87	2.03	2.26
117	Phan (2016)	5.01	1.96	1.97	2.76	4.24	1.24	1.36	1.45
118	Phan (2016)	6.54	2.57	2.45	2.04	5.87	1.82	1.74	1.97
119	Hewitt (2015)	9.43	5.14	2.34	3.12	8.43	1.61	1.96	1.84
120	Hewitt (2015)	4.35	1.55	1.66	1.60	3.74	.96	1.34	1.45
121	Hewitt (2015)	4.35	1.55	1.66	1.60	3.74	.96	1.34	1.45
122	Phan (2016)	5.27	2.08	2.16	2.05	4.63	1.47	1.49	1.33

Table 4.11 Mean syllable duration times, speech rate, and limb tasks for the control group

Participant	Study	SMR mean duration time for tri-syllable in ms	/puh/ mean syllable duration time in ms	/tuh/ mean syllable duration time in ms	/kuh/ mean syllable duration time in ms	IWPM	WPM	SPM	F.R. In sec.	MEI In ms
101	Phan (2016)	440	136	157	144	171.88	170.32	234.37	9.90	60
102	Hewitt (2015)	328	105	99	114	134.33	140.73	189.34	9.72	100
103	Phan (2016)	398	163	171	158	212.23	212.23	297.10	7.53	70
104	Hewitt (2015)	328	115	108	123	189.11	182.23	254.44	14.69	133
105	Hewitt (2015)	405	101	136	134	180.34	185.39	256.18	6.87	170
106	Phan (2016)	394	136	191	183	190.20	188.47	261.09	8.81	160
107	Phan (2016)	394	163	156	155	126.92	126.92	189.23	7.00	130
108	Hewitt (2015)	336	117	140	130	218.00	220.00	312.00	9.24	140
109	Hewitt (2015)	298	102	112	130	210.70	220.74	303.01	8.84	120
110	Hewitt (2015)	315	82	79	92	240.89	245.39	312.19	5.04	80
111	Hewitt (2015)	344	110	107	112	242.70	247.19	343.82	5.44	100
112	Hewitt (2015)	346	103	87	114	221.70	223.74	303.05	8.39	60
113	Hewitt (2015)	518	199	238	246	180.33	180.33	242.62	5.60	90
114	Phan (2016)	436	177	183	180	209.52	209.52	295.23	5.78	80
115	Hewitt (2015)	350	116	108	115	183.71	185.39	244.38	7.56	100
116	Phan (2016)	541	187	203	226	192.98	191.23	270.17	6.44	70
117	Phan (2016)	424	124	136	145	197.60	197.60	258.68	7.03	20 0
118	Phan (2016)	587	182	174	197	203.70	201.85	281.48	7.84	110
119	Hewitt (2015)	843	161	196	184	212.90	209.03	276.77	8.16	140
120	Phan (2016)	374	96	134	145	205.67	207.55	271.70	4.35	100
121	Phan (2016)	374	96	134	145	168.80	168.80	257.80	4.98	60
122	Phan (2016)	463	147	149	133	202.45	198.77	279.75	7.40	60

Chapter V: Discussion

The purpose of this study was to replicate and extend previous research by examining the effects of SRC on the speech mechanism. Previous studies analyzed DDK tasks, intelligibility, speech rate tasks and motor limb movements in collegiate athletes post- SRC (Dolan, 2013; Hewitt, 2015). The current study further extended the Hewitt (2015) study by increasing the sample size in both groups, as well as adding ImPACT composite scores as an additional component. Furthermore, this study aims to provide normative data on the performance of DDK tasks, as well as motor limb tasks of individuals, ages 13-39, with a mixed background of participation and non-participation in recreational sports, and without a current concussion.

5.1 DDK tasks

It was hypothesized that the SRC group would perform slower for the mean syllable duration time and mean total duration time, for both SMRs and AMRs, as compared to the control group. This study confirmed the hypothesis and found the SRC group had slower performances in DDK tasks than the control group. This experimental finding is consistent with existing studies that indicate individuals with TBI perform slower DDK tasks than those without a TBI (Blumberg et al., 1995; Wang et al., 2004; Ergun & Oder, 2008; Dolan, 2013; Hewitt, 2015). However, for mean syllable duration time, a significant difference was only found with AMR /puh/ as compared to the control group. For total mean duration time, AMR /tuh/, with and without intersyllable gap durations, was the only syllable found with significant differences. In contrast, Dolan (2013) and Hewitt (2015) found significant differences in both mean syllable duration time and total mean duration time in SMRs and AMRs for all syllables. It is believed that the larger sample size within this current study may provide an explanation in detecting these effects, as compared to the previous studies (Menzies, Onslow, & Packman, 1999). In

addition, the 4 participants that were added to retrospective data may indicate that the extent of impairments were not the same as the level of impairments found in the other two studies, which may explain why statically significant differences were not detected in all syllables. Also, with the larger sample size, there may have been greater variance thus, reducing the potential to show significance.

In analyzing intersyllable gaps, Wang et al (2004) noted longer intersyllable gap durations in patients with TBI. The experimental findings in this current study found the same effects. However, significant differences were not found. This may suggest further studies need to be conducted in order to detect such significant differences.

In the analysis of AMRs, the experimental findings determined that /puh/ was found to be the fastest syllable produced, followed by the /tuh/ syllable, and lastly the /kuh/ syllable. This finding was also found in the Hewitt (2015) study and Ziegler (2002) study.

Many studies have used DDK tasks to examine patients with motor speech disorders and found overall slowness, inaccuracy, and variability (Gooze et al., 2002 Ziegler, 2002; Bartle et al., 2006; Morgan et al., 2007; McAuliffe et al., 2010). The findings in this study are analogous to the previous studies but for individuals with SRC, indicating widespread neuronal damage may result in the same deficits found in dysarthria. However, more research is needed to determine if these deficits are due to overall motor slowing, caused by SRC, or if the deficits are indeed due to the presence of dysarthria.

5.2 Speech rate

The speech rate analysis did not reveal slower speech rates in the SRC group compared to the control group. In addition, no statistically significant difference was found between groups for this task, which is also consistent with the Hewitt (2015) study.

5.3 Speech intelligibility

The speech intelligibility analysis did not yield significant differences between groups for this task, which is consistent with the Hewitt (2015) study. However, Cahill (2005) did find statistical differences in sentence intelligibility for those with dysarthria (DTBI) when compared to those without dysarthria (NTBI). This study utilized one trained assistant to judge the sentences. Therefore, the credibility of the sentence intelligibility data relied on a single listener. This poses a concern because multiple listeners are recommended to measure intelligibility to establish functional levels or to compare individuals (Yorkston, Beukelman, and Hakel, 1996). Future studies could employ an additional trained assistant to judge the sentences. Those who are judging must not have foreknowledge of the recorded sentences to circumvent the problem of judge familiarity. It is important to note that the examiner (who administered and recorded the sentences) cannot take part in judging the sentences (Yorkston, Beukelman, and Hakel, 1996).

5.4 Motor limb tasks

In analyzing motor limb tasks, the SRC group was found to have slower duration times compared to the control group, indicating a presence of motor limb slowness post-SRC. This finding is consistent with previous SRC research (Dolan, 2013; Hewitt, 2015), as well as other research examining post-TBI individuals (Gagnon, Forget, Sullivan, Friedman, 1998; Monte, Geefen, May, McFarland, Heath, Neralic, 2005; De Beaumont, Theoret, Mongeon, Messier, Leclerc, Tremblay, Ellemberg, and Lassonde, 2009). In the finger repetition task, this current study did not find a statistically significant difference between the SRC group and the control group, which is contrary to the findings from Dolan (2013) and Hewitt (2015). It may be reasonable to believe that the extent of impairments were not the same as the level of impairments found in the other two studies, which may explain why statically significant

differences were not found for the finger repetition task. Also, with the larger sample size, there may have been greater variance thus, reducing the potential to show significance.

5.5 Correlations- spearman correlation coefficient

It was hypothesized that there would be a correlation between DDK tasks and IWPM/SPM. A Spearman correlation coefficient found a statistically significant strong correlation between SMR and speech rate (SPM). This finding indicates that as the SMR mean syllable duration increases SPM also increases and vice versa. However, it should be noted that due to the high number of correlations, it is reasonable that a statistical significance would be detected by chance alone. Therefore, these findings should be interpreted with caution.

It was also hypothesized that there would be a correlation between DDK tasks and motor limb tasks. However, a Spearman correlation coefficient determined there were no statistically significance difference and a weak correlation was found, which is a similar finding in the Hewitt (2015) study.

Another correlation analysis was conducted to find a relationship between ImPACT composite scores and DDK mean duration times, in which the analysis determined a weak relationship between these two tasks.

The correlation analysis continued to examine the relationship between ImPACT composite scores and speech rate. The Spearman correlation coefficient established a moderately strong, positive, correlation between the McVerbal composite score and IWPM. This indicates that as the McVerbal composite score increases, IWPM also increases and vice versa. In addition, a strong, positive correlation was found between McVisual and IWPM. Also indicating that as the McVisual composite score increases, IWPM also increases and vice versa. Again, it should be noted that due to the high number of correlations, it is reasonable that a

statistical significance would be detected by chance alone. Therefore, these findings should be interpreted with caution.

Lastly, the correlation analysis continued to determine if there was a relationship between ImPACT composite scores and motor limb tasks. The analysis revealed no statistical significant difference and correlations ranged from a very weak to weak correlation between these two tasks.

5.6 Clinical implications

Notably, oral DDK tasks examine the reciprocal movements of the lips, tongue, and jaw, which ultimately reflect speech motor capabilities (Blumberger et al, 1995; Wang et al, 2004; Ergun & Oder, 2008). As such, used as a diagnostic tool, this would provide insight on the presence and severity of neurological impairments (Icht & Boaz, 2013). This study acoustically analyzed DDK tasks, which enabled the investigator to determine an overall slowness of DDK rates in individuals with SRC when compared to the non-concussed individuals. This finding is also in agreement with previous research regarding SRC (Dolan, 2013; Hewitt, 2015).

This provides support that clinicians can use DDK tasks as a diagnostic tool for an evidence-based rationale for clinical decisions as it provides a quantifiable measure of speech motor impairments in athletes with SRC. As such, DDK tasks can be used in conjunction with neurocognitive testing to provide a more accurate reflection of the athletes' performance post-SRC.

5.7 Limitations

This study encompasses a few limitations, which poses issues for generalizability. The limitations include sample population, reliability of retrospective data, and the level of fatigue possibly experienced by the SRC group.

The sample was a convenience sample comprised of UTEP students from various departments. Adolescent participants were recruited by referrals from the UTEP students, which included siblings and family members from retrospective data from the Hewitt (2015) study. Additionally, a very small percentage of participants were involved in recreational sports from the control group, which did not match the SRC group. The number of participants in the control group was decreased to match the number of participants in the SRC group, according to gender and age. However, the number of males and females in the control group did not equal the number of males and females in the SRC group. This was also an issue when age matching between groups. These limitations present a concern for the external validity of the study.

Another limitation is the reliability of the retrospective data utilized in this study. Though the same methods and procedures were used in this study as the Hewitt (2015) study, reliability is a concern due to the variability among investigators. Inter- and intra-reliability measures were taken in this current study and in the Hewitt (2015) study. However, it is unknown if the same reliability measures were used for the data in the Dolan (2013) study. This provides concerns for the internal validity of this current research.

Lastly, fatigue in SRC group is a concern to the internal validity of this study. Though conditions were established to control for fatigue, there were not enough individuals in the SRC group beginning with DDK tasks and motor limb tasks. Further randomizing of the motor speech and motor limb tasks is highly recommended, with focus on DDK tasks and motor limb tasks starting at the beginning of the assessment.

5.8 Considerations

It is recommended that further studies aim to collect a larger sample size for both groups to achieve normal distribution. In addition, it is recommended that groups be matched by age, gender, and education.

Though this current study did not eliminate any participants with hearing loss in the SRC group, it is important to note that inclusion criteria should not exclude participants with hearing loss, as this could be a result of the concussion itself.

Further studies should include a perceptual judgment of intelligibility for the sentences completed in the SIT tasks of the SRC group. The listeners of this perceptual task should include naïve listeners from professionals in the SLP field, outside professionals, and graduate SLP students. This task would provide insight on the perceptual ability to distinguish deviant speech characteristics within the SRC group.

5.9 Conclusions

The primary concern regarding SRCs among athletes is the lack of a sensitive measure to detect subtle deficits after an injury, thus leading to premature return-to-play decisions (Theye & Mueller, 2004). Despite the amount of literature highlighting the risks of cumulative effects of SRC, return-to-play decisions have been based on experience rather than evidence (Theye & Mueller, 2004). This study provides evidence that motor speech slowing can occur in SRCs, suggesting deficits may be due to the sequelae associated with the injury. This research study also provides further support to existing literature regarding the slowing of motor limb effects post-SRC/mTBI (Monte et al., 2005; De Beaumont et al., 2009; McCrory et al., 2009; Edwards & Bodle, 2014).

Individuals may exhibit different levels of impairment, as well as vary in signs due to several influencing factors such as sport, gender, age, and history of concussion (Aubry et al.,

2002; Broglio & Guskiewicz, 2009). Regardless of which signs are present, it is critical for the health professionals recognize that any sign related to a concussion is enough to withhold the athlete from returning to the field (Broglio & Guskiewicz, 2009). A premature decision to return to play after a concussion may increase the likelihood of sustaining repeated concussions during athletic participation (Schatz et al., 2005), and risking the potential for further damage that may be manifest as a motor speech disorder, such as dysarthria (McKee et al., 2009). Therefore, diagnosis of concussion should be based on the comprehensive assessment to examine any deficits displayed by the athlete (McCrory et al., 2013). This comprehensive assessment should also include a motor speech examination to assess abnormalities that may be present in the athlete's speech due to possible cranial nerve involvement upon sustaining the injury (Cannito, 2014).

This study provides further evidence of motor slowing in motor speech and motor limb movement in athletes post-SRC. Motor speech assessments can provide insight into the presence of a deficit after sustaining a SRC, thus enabling the health professional to make adequate, and safe return-to- play decisions.

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Curriculum Vita

Linda Nguyen Phan was born in Dallas, Texas. She is the only daughter of Khuong Phan. Linda Nguyen Phan graduated from Bowie High School, Dallas, Texas. She received her Bachelor of Science in Education, and graduated with summa cum laude, from The University of Texas at Arlington in the summer of 2010. During her teaching residency, she became passionate about advocating for those with communication disorders, in which she decided to complete her teaching residency, obtain a teaching certification, and further pursue a degree in Speech-Language Pathology. She was then accepted to the Master's Program of Speech-Language Pathology, at The University of Texas at El Paso, in the fall of 2014. She received the Grace Middleton Endowed Scholarship Award from the Texas Speech-Language-Hearing Foundation in the spring of 2015. She later received the Madeline Brand Endowed Scholarship, also from the Texas Speech-Language-Hearing Foundation in the spring of 2016. She worked as a research assistant at the Concussion Management Clinic, at the University of Texas at El Paso, under the supervision of Dr. Anthony P. Salvatore. This experience sparked her interest in sport-related concussions and in her current research study. During her graduate studies, she also completed additional courses to receive a certification in Concussion Management.