The Effects of a Sport-Related Concussion on the Motor Speech and the Motor Limb Movements: Examining Oral Diadochokinesis, Speech Rate, and Limb Tasks

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THE EFFECTS OF A SPORT-RELATED CONCUSSION ON THE MOTOR SPEECH MECHANISM AND THE MOTOR LIMB MOVEMENTS: EXAMINING ORAL DIADOCHOKINESIS, SPEECH RATE, AND LIMB TASKS

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DEDICATION

I would like to dedicate this thesis to God, for allowing me to reach this point in my life and helping me accomplish this goal; to my mother, for her unselfish sacrifice, love, and encouragement; to my husband, for helping me focus and for his continued support throughout my graduate studies; to my brothers, for always believing in me and pushing to be the best that I can be; and to Dr. Anthony P. Salvatore, Ph.D, for igniting my passion in sport-related concussions. Thank you all for your love and support.
THE EFFECTS OF A SPORT-RELATED CONCUSSION ON THE MOTOR SPEECH MECHANISM AND THE MOTOR LIMB MOVEMENT: EXAMINING ORAL DIAODOCHOKINESIS, SPEECH RATE, AND LIMB TASKS

by

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THESIS

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Background: Motor speech disorders, such as dysarthria, are a common sequelae reported after traumatic brain injuries. However, there is limited research on the effects of sport-related concussions (SRC) on motor speech disorders.

Aims: The current study aimed at replicating and extending a previous research study, Dolan (2013), conducted at the University of Texas at El Paso. In her study, Dolan (2013) incorporated and evaluated motor speech tasks: sequential motion rates, and motor limb tasks: movement execution initiation and finger repetition, in athletes following a sport-related concussion. The current study duplicates Dolan’s (2013) study. In addition, it investigates the effects of a SRC on alternating motion rates, speech rate, and intelligibility in a sentence repetition task.

Methods: Motor speech and motor limb tasks were investigated in 18 individuals (7 males, 11 females; age = 18.78 years ± 2.37) following a SRC and 18 individuals (7 males, 11 females; age = 19.66 years ± 3.03) in a control group, closely matched by age and education. Oral diadochokinesis (DDK) tasks: sequential motion rates and alternating motion rates were measured and acoustically analyzed using Kay Elemetrics: CSL, model 4500. Speech rates were attained using the computerized Sentence Intelligibility Test. 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: The results demonstrate slower DDK syllable duration and total duration times in athletes following a SRC compared to individuals in the control group. Additionally, individuals following a SRC showed slower finger repetition duration and movement execution initiation times in comparison to the control group. Although, speech rate and speech intelligibility is not significant, speech rate did differ; slower speech rate is still noted in athlete’s post-SRC in comparison to the control group.

Conclusions: Sport-related concussions do have a significant impact on the motor speech and the motor limb mechanisms, further adding to the already known consequences.
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CHAPTER I
INTRODUCTION

As a former high school educator, I had the opportunity to mentor several student-athletes. Many stated their participation in sports stemmed from an enjoyment of the game or family tradition, yet others, had aspirations to become the next Joe Montana or Michael Jordan. Athletes are pushed to perform on the field in response to parent, coach, and peer expectations or demands. Other athletes are driven by their expectations, dreams, and/or financial needs and wants. Many of these demands may, at times, contribute to an athlete’s willingness to overlook the significance of a concussion- regardless of the level at which they play: middle school, high school, collegiate, or professional. Furthermore, the lack of awareness of what a concussion is, often impacts their failure to report it. In a recent study, Register-Mihalik and colleagues (2013) evaluated high school student knowledge and attitudes about concussions and reported the most common reason for not reporting a concussion is that the athlete did not think the injury was serious enough to report (70.2%), followed by not wanting to be removed from the game (36.5%).

According to the Centers for Disease Control and Prevention (2010), 138 people die every day, in the United States, from traumatic brain injuries (TBI). It is estimated that the yearly incidence of TBI is between 1.6 million and 3 million for recreational sports (ICD, 2010). A large percentage of these victims are within the pediatric range, 5-18 years old, which account for the majority of sports-related concussions (Halstead & Walter, 2010). Gessel et al., (2007) reported that the majority of concussions, at the high school level, result from participation in the following sports: football- 40%, girl’s soccer- 22%, boy’s soccer- 15%, and girl’s basketball 10%. However, all of the above facts are not a complete representation of the true incidence of
sport-related concussion (SRC), since many concussions go unreported (Grady, 2010). In fact, many individuals just disregard it, without knowing they have suffered a mild traumatic brain injury (mTBI).

The statistics are alarming and should be of concern to every parent and athlete; especially parents with children playing sports, within the pediatric range since their brain is still developing (Halstead & Walter, 2010). Understanding the consequences of a concussion can be challenging. Injuries are not immediately noticeable and can go undetected. Because there is no structural damage or obvious physical abnormality immediately after a concussion, athletes and parents, all too often, fail to understand its impact, severity, and complexity in its entirety.

1.1 Defining a Mild Traumatic Brain Injury (mTBI)/Concussion

A concussion is a subset of traumatic brain injury (TBI), classified as a mild traumatic brain injury (mTBI), defined as a “complex pathophysiological process affecting the brain, induced by biomechanical forces” (McCrory et al., 2013). A biomechanical force is a direct blow to the head, neck, or body where significant force is transmitted to the head as a result of the impact (McCrory et al., 2013). The brain experiences forces of linear, rotational, and angular acceleration that result in a wide spectrum of severity, contingent upon the site of the impact of the traumatizing force and direction (Kilbourne, et al., 2009). Other variables, such as history of concussion and length of retrograde or anterograde amnesia also play a factor in the severity of the concussion. Following an mTBI, the brain goes into a state of temporal neuronal dysfunction, an event called Neurometabolic Cascade, which is a result of ionic shifts, altered metabolism, impaired connectivity, or changes in neurotransmission (Giza and Hovda, 2001).

Acceleration injuries, linear and rotational, are caused by abrupt acceleration or deceleration of the head, which are rather prevalent in sport-related concussions (Bailes and
Acceleration injuries occur when the head (or body) moves quickly through space and comes to an abrupt stop (impacting an object), or when the head is at rest and is suddenly accelerated (e.g. being struck by an object) (Brookshire, 2007). Linear acceleration transpires when the impact of the force is aligned with the center of the axis of the head; whereas, rotational acceleration occurs when the head is impacted off-center, causing the head to rotate at an angle away from the point of impact (Brookshire, 2007). According to Brookshire (2007), linear (translational) forces cause focal damage to the meninges and the specific brain tissue where the brain is compressed against the skull. Alternatively, rotational injuries are concentrated at the boundaries of gray and white matter fiber tracts: internal capsule, corpus callosum, and brainstem (Brookshire, 2007). Therefore, both linear and rotational injuries result in neuronal dysfunction affecting primarily the area(s) of impact.

Headache is the most commonly reported symptom following a concussion (Conidi, 2012), and confusion is known as the hallmark of a concussion (Cubon et al., 2011). However, other signs and symptoms may be present as well. Salvatore and Fjordback (2011) delineate the following clinical signs and symptoms following a sport-related concussion: cognitive – communicative function – retrograde or anterograde memory loss, word retrieval difficulties, poor organizational skills – physical manifestations – loss of consciousness, dizziness, decreased response time, and motor speech or impaired balance – or behavioral symptoms – disorientation, confusion, and reduced attention to task – in an individual post-concussion. Any range of the abovementioned symptoms may be present following a SRC. However, concussion symptoms will present differently in every individual, and the onset of these symptoms may also vary. For the purposes of this paper, the term concussion and mTBI will be interchangeably used throughout.
1.2 Imaging Studies

Imaging studies are a promising source providing different ways to identify neuronal dysfunction or areas of damage following a SRC. Diffusion Tensor Imaging (DTI), for instance, is sensitive in detecting white matter anomalies in the cortex following a SRC (McCrae, 2008). Cubon and colleagues (2011) used DTI to examine white matter abnormalities in athletes following a SRC, with persistent symptoms one-month post-injury. The largest areas affected are found in the left hemisphere of the following brain regions: “sagittal stratum (including the inferior longitudinal fasciculus and inferior fronto-occipital fasciculus), retrolenticular part of the internal capsule, the posterior thalamic radiation (including optic radiation), the acoustic radiation, and the superior longitudinal fasciculus, anterior and superior to the part of the superior longitudinal fasciculus” (Cubon et al, p. 195, 2011). Additionally, in the superior temporal lobe, atypical white matter is also found along the acoustic radiation, which contain projection fibers that connect the medial geniculate body of the thalamus to the primary auditory cortex of Heschl’s gyrus (Cubon et al, 2011). All of these areas of impact are significant, for they indicate that damage is primarily focused on white matter fiber tracts of the brain. According to Park and colleagues (2008), imaging studies and serum biomarkers demonstrate that white matter injury is gradual, but nonetheless an evolving process. Additionally, following an mTBI, white matter lesions may be the determinant of ongoing symptoms, as well as patients’ increased susceptibility to future traumatic events (Park, Bell, and Baker, 2008).

1.3 Consequences of a Mild Traumatic Brain Injury

The consequences of a SRC can vary from temporal neuronal dysfunction, and although rare, to death. The leading cause of death from athletic head injury is intracranial hemorrhage (Cantu, 1997). Cantu (1997) describes four different types of intracranial hemorrhages that may
result from a SRC: epidural or extradural hematoma, subdural hematoma (most common as a result of sports injury), intracerebral hematoma and subarachnoid hemorrhage. In a 1999 study, Powell & Barber-Foss report the incidence of SRCs in a three-year period. Out of 1,219 mTBIs, they report four cases of subdural hematoma and two cases of intracerebral hematoma; however, no deaths are reported (Powell & Barber-Foss, 1999). Additionally, other ramifications of a concussion include, but are not limited to, post-concussion syndrome, chronic traumatic encephalopathy, and second impact syndrome.

1.3.1 Post-Concussion Syndrome (PCS)

Post-concussion syndrome (PCS) is described as persistent symptoms that have not subsided within a certain amount of time post-concussion injury. The *International Classification of Diseases, 10th Revision* (1992) define PCS as having more than three of the following symptoms: headache, dizziness, fatigue, irritability, insomnia, difficulty concentrating, memory difficulty, and intolerance to stress, emotion, or alcohol, beyond four weeks of the concussion. PCS has previously been documented to be present in both high school and collegiate athletes following a SRC (Halstead et al., 2010; McCrae, 2008).

1.3.2 Chronic Traumatic Encephalopathy (CTE)

The effects of repeated sport-related concussions are known to accumulate over time, and some individuals develop long-lasting or progressive symptoms (McKee et al., 2009; Gardner, 2013) a phenomenon called chronic traumatic encephalopathy (CTE). Chronic traumatic encephalopathy is characterized by a number of neuropathological elements shared with various neurodegenerative diseases such as Alzheimer’s disease (Morley, W.A., & Seneff, S., 2014). Conidi (2012) outlines the signs and symptoms associated with CTE in debilitating stages: Stage 1- loss of emotional response and mild psychosis; Stage 2- social instability, erratic behavior,
memory loss, and mild Parkinsonism; Stage 3- cognitive dysfunction progressing to full-blown Parkinsonism, speech and gait abnormalities, dysarthria, dysphagia, and ocular abnormalities/ptosis. There have been 17 cases, in deceased contact sport athletes, identified to have chronic traumatic encephalopathy (Conidi, 2012). Dr. Ann McKee, director of the CTE Center at Boston University, studies the impact of concussion on former athlete’s postmortem brains. To date, she has found CTE in 64 NFL players, four NHL players, 18 college athletes and four high school players (Kuzydym, 2014).

1.3.3 Second Impact Syndrome (SIS)

In addition to the abovementioned consequences, there is another significant consequence following SRC, that although rare, merits attention: second-impact syndrome. SIS is a result of an athlete sustaining a head injury- concussion or worse- who receives a second injury to the head before the brain has reached homeostasis, where symptoms have completely resolved (Cantu, 1998). For the pediatric population, this condition is termed as malignant brain edema, which consists of “rapid neurologic deterioration from an alert conscious state to coma and sometimes death, minutes to several hours after head trauma” (Cantu, 1998, p. 43). The pediatric population is at highest risk for Second-Impact Syndrome. The majority of the SRCs resulting in SIS are athletes younger than 20 (Halstead & Walter, 2010).

1.4 Impact of SRC in Adolescents and Adults

Adolescents and adults might not respond the same to a SRC, due to premature development in the adolescent brain. In a study evaluating the development of cognitive abilities in 23 healthy children (ages: 7-18), Nagy and colleagues (2004) conclude that cognitive development, during the later part of childhood, is correlated with maturation of white matter. Additionally, axons, which make up major fiber pathways in the brain, such as those of the
corpus callosum or the corticospinal tract, continue to develop throughout childhood and adolescence (Paus, 1999). Likewise, Gaillard and colleagues (2000), explain that myelination in cortical association areas, such as those in the frontal lobe, continue to develop through adolescence. For this reason, adolescent athletes might be more vulnerable to a SRC than adult athletes.

Baillargeon et al., (2012) compared neuropsychological and neurophysiological assessments in children, adolescents, and adults, following a SRC, and they conclude that adolescents are more vulnerable to a concussion in comparison to children and adults. Additionally, after one-year post-injury, these same adolescents had persisting deficits, specifically with working memory. Another study (Hunt & Ferrara, 2009) comparing neuropsychological testing within typical healthy high school students showed that the older the athlete, the better the performance of information processing, attention, and motor tests.

1.5 Recovery in Adolescents and Adults

Recovery, following a SRC, is variable among individuals. However, most of the research has shown that 80-90% of concussions, in adults, resolve within a 7-10 day period; however, longer recovery times are designated to the adolescent athlete (McCrory, 2013).

Several studies focusing on the adolescent athlete, following a SRC, have reported recovery times beyond 7-10 days. Barr and colleagues (2012) tracked SRC recovery measuring brain electrical activity in high school students. Their study reveals abnormalities in the brain beyond 7-10 days, and even at 45 days post-injury. They conclude that adolescents continue to exhibit an alteration of brain functioning several weeks post-injury (Barr, et al., 2012). Additionally, McCrae and colleagues (2010) conducted electroencephalogram (QEEG) studies: sensitive in reflecting changes in brain function, in 28 collegiate and high school athletes
following a SRC. Electrophysiological recovery showed significant differences between the control and the concussed group, showing QEEG abnormalities from baseline to day 8, but no significant differences at day 45 (McCrae, et al., 2010).

Zuckerman and colleagues (2012) used neuropsychological testing to manage recovery time between adolescents and adults. They concluded that athletes, ages 13-16, took several days longer to return to their neurocognitive and symptom baselines in comparison to athletes 18-22 years old. The average day to return to baseline performance for the adults was 4-6 days, whereas, the average recovery time for adolescents was 7-8 days (Zuckerman, et al., 2012). In another study, Field and colleagues (2003) also used myriad neuropsychological tests, 24 hours to 7 days post-injury, following a SRC, and discovered similar results. The adolescent athlete demonstrates slower neuropsychological recovery and report more symptoms (still impaired at 7 days post-injury) in comparison to collegiate athletes (resolved by 7 days post-injury) (Field et al., 2003).

Overall, SRCs can result in myriad complications, which in turn, can affect adults and adolescents differently. Because linear and rotational injuries differ in the area of the brain that is impacted, all individuals will be impacted differently depending on various variables: history of a concussion, place of impact, severity of damage, and presence of continued symptoms. Due to the variety of neuronal dysfunction affecting the brain, it is plausible that this neuronal dysfunction can impact both the motor speech and motor limb movements of an individual. Thus, severe consequences may result in motor speech and/or limb slowness or dysfunction.
CHAPTER II
LITERATURE REVIEW

The existing research in SRC has established that the consequences of injury are not pertinent to just one area of the brain. Different brain regions and white matter fiber tracts are affected. However, there remains a lack of understanding and uncertainty on the impact of motor speech disorders following a SRC. Motor speech disorders, according to Duffy (2013) result from neurologic impairments that consequently affect the planning, programming, control or execution of speech. Motor speech disorders include dysarthria and apraxia of speech.

Dysarthria is defined as a group of neurologic speech disorders that may reflect abnormalities in all or some of the following speech parameters: strength, speed, range, steadiness, tone, or accuracy of movements required for breathing, phonation, resonance, articulation, or prosody (Duffy, 2005). Apraxia of speech is an impairment of the planning or programming of sensorimotor commands vital for directing movements resulting in normal speech (Duffy, 2005). However, apraxia of speech is rarely reported in individuals post-TBI (Murdoch & Theodoros, 2001).

Dysarthria, nonetheless, has been reported in many studies as an outcome, post-TBI (Cannito, 2014; Murdoch, Kuruvilla, Goozee, 2012; Toshniwal & Joshi, 2010; Vitorino, 2009; Ergun & Oder, 2008; Wang, Kent, Duffy, & Thomas, 2005; Wang, Kent, Duffy, Thomas, & Weismer, 2004; Cahill, Murdoch, & Theodoros, 2002; Ziegler, 2002; Goozee, Murdoch, & Theodoros, 2001; Goozee, Murdoch, Theodoros, and Stokes, 2000). Despite the TBI literature on the topic, there is limited research exploring dysarthria as an outcome of SRC, and although dysarthria is not a common consequence, it has been documented to occur (Cannito, 2014). Two studies, Murdoch, Kuruvilla, and Goozee (2012) and Theodoros, Murdoch & Goozee (2001),
have reported, at least one or more, individuals with characteristics of dysarthria following a sport-related TBI.

2.1 **Dysarthria in Pediatric and Adult Populations**

Wang and colleagues (2004) emphasize that location of lesion sites and the extent of brain damage, post-TBI may vary across individuals, causing neuronal control difficulties impacting myriad speech subsystems: respiration, phonation, resonation and articulation (Wang, 2004). Cahill et al., (2002) perceptually analyzed the four speech subsystems: articulation, resonance, phonation, and respiration parameters in 24 individuals: individuals with dysarthria post-TBI (DTBI), individuals without dysarthria post-TBI (NDTBI), and a control group: ages 5-18. Overall, the TBI group demonstrated deviations in prosody: lack of pitch variation, loudness level, and increased phrase length; respiration: decreased breath support; resonance: hypernasality; articulation: increased length of phonemes, imprecision of vowels, and consonants and decreased overall intelligibility in comparison to the control group. However, no significant differences were noted in perceptual speech characteristics when comparing the NDTBI group to the control group.

Toshniwal & Joshi (2010) evaluated residual speech impairments in three subjects with different types of dysarthria, ages: 24, 24, and 60, post-TBI. Perceptual parameters revealed slower speech rates, affected prosody (duration of stressed words is lengthened), poor intelligibility and slurred speech in these individuals.

Vitorino (2009) compared 15 children (age at injury, range: 4 – 14) and 15 adults (age range: 17-53) post-TBI using perceptual and instrumental analysis. Adults exhibited a greater number of deviant speech dimensions, specifically with higher mean rating for strained-strangled voice, in comparison to the pediatric group. Sixty-percent of adults were judged with moderate to
severe intelligibility, whereas, only one child presented with a “just-noticeable” level of intelligibility.

2.2 Oral Diadochokinesis

Oral diadochokinesis (DDK) are sensitive measures in detecting mild (or any unobvious) neuromuscular impairment of the lips, tongue and velum; further assisting in the assessment and differential diagnosis of emerging progressive neurological deterioration (such as dysarthria), and sensitive in measuring change at the impairment level (Gadesmann & Miller, 2008). DDK tasks include both: alternating motion rates and sequential motion rates. These measures compare the speech motor demands of a single sound repetition task versus a syllable sequence repetition task (Williams & Stackhouse, 2000).

Alternating motion rates (AMRs) are useful tasks in judging speed and regularity of reciprocal jaw, lip and anterior/posterior tongue movements, while also detecting articulatory precision, adequacy of velopharyngeal closure and respiratory and phonation support (Duffy, 2013). AMRs are characterized by the steady repetition of a monosyllable such as, /puh,puh,puh…/ without any variance in syllable type; this task may also include monosyllables: /tuh/ and /kuh/ (Williams & Stackhouse, 2000).

Sequential motion rates (SMRs) are useful in detecting deficits of sequential movements from one articulator to another (Duffy, 2013). SMRs are characterized by repeating three different syllables, put together, continuously: /puhtukuh, puhtukuh, puhtukuh…/ (Williams & Stackhouse, 2000).

DDK tasks are non-lexical tasks, which assess articulatory and speech motor planning: neuromotor skill versus linguistic skill (Williams & Stackhouse, 2000). Repetitions of these non-meaningful/lexical syllables are likely to yield a measure of speech motor ability less
contaminated by linguistic factors than real word or non-word repetition (Williams and Stackhouse, 2000). For the purposes of the current study, DDK tasks will be comprised, of both AMRs and SMRs. However, because a fixed number of syllable occurrences will be elicited for each DDK task, a rate will not be reported rather the total mean duration (with and without gap durations) and mean syllable duration will be measured and reported.

### 2.3 Speech Rate and Speech Intelligibility

Individuals with dysarthria, post-TBI, also demonstrate impaired speech rates and reduced intelligibility. The Assessment of Intelligibility of Dysarthric Speech (ASSIDS) is a frequently used assessment to quantify single word and sentence intelligibility, along with measuring rate of speech (Goozee, et al., 2000). The Sentence Intelligibility Test (SIT), too, can calculate the same speech parameters as the ASSIDS. However, it does not yield results for single words. The speech measurements that can be derived from these tests are: speech intelligibility- overall measure of understandability of an individual’s speech; total words per minutes (WPM)- total words produced by an individual and the duration it took them to produce the words; intelligible words per minute (IWPM)- accuracy of the words produced by the individual and speaking rate; communication efficiency ratio (CER)- rate of intelligible speech produced by a speaker with dysarthria divided by the typical rate of intelligible speech, which was determined to be 190 WPM for the control group acquired by Yorkston et al., (1981).

Cahill and colleagues (2002) report significant differences in intelligibility and speech rates using the ASSIDS in individuals with (DTBI group) and without dysarthria (NDTBI group) post-TBI in comparison to a control group. The results are displayed in Table 2.1 below.
Table 2.1 ASSIDS results for Cahill et al., (2002) study.

<table>
<thead>
<tr>
<th></th>
<th>DTBI group</th>
<th>NDTBI group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intelligibility</td>
<td>88.05 (24.49)</td>
<td>99.06 (0.49)</td>
<td>99.77 (0.33)</td>
</tr>
<tr>
<td>WPM</td>
<td>117.70 (43.66)</td>
<td>139.90 (38.44)</td>
<td>175.36 (27.88)</td>
</tr>
<tr>
<td>IWPM</td>
<td>108.27 (48.80)</td>
<td>138.67 (38.31)</td>
<td>174.95 (27.90)</td>
</tr>
<tr>
<td>CER</td>
<td>0.57 (0.26)</td>
<td>0.73 (0.20)</td>
<td>0.92 (0.15)</td>
</tr>
</tbody>
</table>

Standard deviations are represented in parenthesis

In another study, Goozee and colleagues (2000) also used the ASSIDS to measure speech rate and intelligibility in a 19-year-old with spastic-ataxic dysarthria, post-TBI. Sentence intelligibility was 98.61%, speaking rate was reported as 166 WPM, and IWPM was 164.

However, there are no current studies reporting intelligibility or speech rate measures following a SRC. For the purposes of this study, the Sentence Intelligibility Test (SIT) for Windows (Yorkston, Beukelman, & Tice, 1996) will be used to quantify sentence intelligibility, rate of total words per minute, rate of intelligible words per minute, and communication efficiency ratio.

2.4 Motor Limb Tasks

Since SRCs represent a mild form of TBI, it is plausible that the consequences may result in motor execution slowness or bradykinesia (De Beaumont, Theoret, Mongeon, Messier, Leclerc, Tremblay et al., 2009). De Beaumont et al., (2009) measured cognitive and motor functions in former university athletes (mean age = 60 years), 15-25 years post-SRC to a control group (mean age = 59 years) - 21 athletes with no history of SRC. They concluded that relative to controls, the concussed group exhibited cognitive and motor system alterations, showed reductions on neuropsychological as well as electrophysiologic measures of episodic memory and frontal lobe functions, displayed significant motor execution slowness on a diadochokinesia task, and significant delays were found in P3a and P3b waveforms elicited by target stimulus.

Additionally, Dolan (2013) used a finger repetition and movement execution initiation time task to measure motor limb effects, in collegiate athletes, following a SRC. A statistically
significant difference was found in the 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 8.14 seconds ± 2.28 in comparison to 5.78 seconds ± 1.25 for the control group. However, no significant differences were found in the movement execution initiation time task between the groups.

Gasser et al. (2009) analyzed differences between motor limb movements, across age, and noted a strong improvement of motor speed for finger repetition tasks. Improvement was found to be faster at an early age (age 5-10) and slower towards adolescence (age 12-18). The age effect was observed to be stronger for the sequential finger and alternating hand task (Gasser et al., 2009).

For the purposes of this study, there will be two motor limb tasks: a sequential finger repetition task and a movement execution initiation time task.

2.5 The Motor System

Murdoch, Theodoros, & Stokes (2000) report that damage to the neuromuscular system regulating speech, as it occurs after a TBI, can disrupt the fine motor control skills, subsequently resulting in dysarthria- for both children and adults. Therefore, because a mTBI results in a “diffusion of neural damage and can produce a wide array of physiological anomalies” (Morgan, Leigeois, & Occomore, 2007) it is worthy to consider the impact it has on an athlete’s motor system.

Typical motor performance is contingent upon the activity of three systems: pyramidal system, vestibular-reticular system, and the extrapyramidal system (Brookshire, 2007). The pyramidal system is responsible for most volitional movements; while the extrapyramidal system arises from diverse location in the central nervous system (such as basal ganglia) and projects to
both cranial and spinal nerves; they adjust muscle tone and posture (Brookshire, 2007). The vestibular-reticular system is responsible for maintaining alertness, balance, and orientation of the body (Brookshire, 2007).

Both motor speech and limb movements are executed within the primary motor cortex—each sharing a different amount of cortical area in the pre-central gyrus. However, even though they are mapped in the same cortical area, these motor neurons communicate down two different pyramidal tracts: corticobulbar tract and corticospinal tract (Duffy, 2005). The corticobulbar tract is a motor pathway that begins in the cerebral cortex and connects with motor neurons of the brainstem (Brookshire, 2007). The motor neurons of the brainstem control muscles and cranial nerves of the face, head and neck (Brookshire, 2007). Likewise, the corticospinal tract is a motor pathway that begins in the cerebral cortex and connects to motor neurons in the spinal cord responsible for volitional movement of the muscles responsible for movement of trunk and limbs (Brookshire, 2007). Damage to any one of these systems will produce a dysfunction of motor performance (Brookshire, 2007).

### 2.6 Brain Regions Involved

Although both motor speech and motor limb movements derive from the same anatomical area of the motor cortex, they are unique systems.

Speech uses particular neuroanatomical and neurophysiological pathways to function (Duffy, 2013). It is a complex process involving the auditory, somatosensory, and motor regions, which are represented in the temporal, parietal, and frontal lobes of the cerebral cortex (Guenther, 2006; Gracco, 1992). Additionally, speech production cannot be carried out without the involvement of subcortical structures such as the cerebellum, basal ganglia, and the brainstem (Guenther, 2006). In addition to brain regions, the cranial nerves also play a pivotal role in speech production.
role in innervating speech mechanisms and damage to any of these nerves may also cause
dysarthria. Goozee et al., (2000) reported inaccurate tongue movements in an individual post-
TBI. This individual reported having difficulty in decelerating the tongue quickly, a problem of
overshooting articulatory placement.

Motor limb processes, specifically involving finger movements, require the activation of
bilateral supplementary motor cortex and bilateral premotor cortex, with either right or left
activation of primary motor cortex during execution: depending on the hand being used (Lee,
Chang, Roh, 1999). Additionally, each of these motor areas receives unique cortical and
subcortical inputs, which can derive from, but not limited to the somatosensory cortex, posterior
parietal area, cerebellum, thalamus, basal ganglia each with its own pattern (Krakauer & Ghez,
2000). Therefore, both motor speech and limb movements are complex processes involving more
than just one area of the brain and multiple neuronal pathways to carry out their movements.

The purpose of the current study is to examine the impact of motor speech and motor
limb movements, in adolescents and adults, during the acute and subacute phase following a
SRC. An exploration of the effects of the following speech parameters: DDK tasks,
intelligibility, and speech rate following a SRC will be investigated to define the clinical value in
the diagnosis of motor speech effects. The current research study is focused on the following
objectives.

The first objective of the current study is to replicate and extend the previous research
study: Dolan (2013). In her study, Dolan (2013) evaluated motor speech: SMRs, and motor limb
tasks: movement execution initiation time and finger repetition task, in athletes, following a
SRC. This study will replicate these same tasks and will further extend the study by increasing
the sample size in both groups and investigating additional speech mechanism components such
as speech rate, intelligibility, and AMRs. Retrospective data from Dolan (2013) will be used in combination with the current study data, to increase statistical power for the current SRC group.

The second objective of the current study is to see if there are a statistical correlation between DDK tasks and motor limb tasks between the groups. It is of interest to see if there is any relationship between the duration of motor limb movements with those of motor speech movements.

This research study is a group design consisting of a SRC group: athletes following a SRC and a control group: individuals with no current (within the past year) diagnosis of a concussion. Both groups will be measured across the DDK tasks: mean syllable duration and total mean duration times of DDK and motor limb tasks: finger repetition and movement execution initiation time tasks, intelligibility and speech rate. The research questions and hypotheses driving the current study are the following:

1. Is there a statistically significant difference in DDK mean syllable duration between the SRC group in comparison to the control group?
   
   *Hypothesis:* The SRC group will have slower DDK mean syllable durations in comparison to the control group.

2. Is there a statistically significant correlation between DDK total mean duration in comparison to total mean duration on the motor limb tasks between groups?
   
   *Hypothesis:* Total mean duration of the motor limb tasks will be statistically correlated with DDK tasks for both groups.

3. Is there a statistically significant difference in total mean duration for limb tasks between the SRC group in comparison to the control group?
Hypothesis: The SRC group will take more time in carrying out the motor limb tasks in comparison to the control group.

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

Hypothesis: The SRC group will exhibit statistically significant slower intelligible words per minute in comparison to the control group.

5. Is there a statistically significant correlation between IWPM and DDK mean syllable duration between the SRC group in comparison to the control group?

Hypothesis: IWPM will be statistically correlated with DDK mean syllable duration across both groups.
CHAPTER III

METHODS

The current study was reviewed and approved by the Institutional Review Board (IRB) at the University of Texas at El Paso (UTEP). Signed informed consent was obtained from all participants- to include parents, if participants were under the age of 18. The IRB reference number for this study is 552011-2.

3.1 Participants

Initially, 13 participants were recruited for the SRC group and 57 participants were recruited for the control group. Of the 13 individuals recruited, in the current study, for the SRC group, three individuals were dismissed due to the following reasons: one athlete began experiencing symptoms during testing and decided to withdraw, and two athletes’ data could not be accessed due to technical difficulties- their data had to be discarded. Out of the 57 participants recruited in the control group, seven participants were dismissed due to eligibility requirements. After collection of all data, the groups were then reduced in an attempt to create equal groups and to closely match the participants by age and education.

Therefore, the SRC group consisted of 18 athletes diagnosed with a concussion within a one-month period. Of the 18 athletes who sustained a concussion, seventeen were sport-related concussions at the junior high, high school, or collegiate level. One athlete’s concussion was a result of a motor vehicle accident (MVA). Out of the 18 athletes, 10 were recruited in the current study while the other 8 athletes were retrospective data from Dolan’s (2013) study. Detailed demographic information for the SRC group is displayed in Table 3.1.

Inclusion criteria for the SRC group were the following: (a) age range: 13-40; (b) no hearing loss; (c) no history of drug or alcohol abuse; (d) no previous history of psychiatric
illnesses; (e) no previous history of a learning disability; (f) no history of seizures, brain tumors, etc.; (g) current diagnosis of a concussion; (h) English as a dominant language.

**Table 3.1** Demographic information for the SRC group.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age</th>
<th>Concussion Type and Level</th>
<th>History of Concussion</th>
<th>Post Injuy</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>F</td>
<td>23</td>
<td>MVA</td>
<td>0</td>
<td>3 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>202</td>
<td>M</td>
<td>13</td>
<td>Sport: Football (Middle School)</td>
<td>3</td>
<td>7 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>203</td>
<td>F</td>
<td>21</td>
<td>Sport: Cheerleading (Collegiate)</td>
<td>0</td>
<td>3 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>204</td>
<td>M</td>
<td>18</td>
<td>Sport: Ice Hockey (Semi-Professional)</td>
<td>2</td>
<td>1 day</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>205</td>
<td>F</td>
<td>18</td>
<td>Sport: Cheerleading (Collegiate)</td>
<td>2</td>
<td>2 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>206</td>
<td>M</td>
<td>20</td>
<td>Sport: Cheerleading (Collegiate)</td>
<td>3</td>
<td>4 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>207</td>
<td>M</td>
<td>17</td>
<td>Sport: Football (High School)</td>
<td>1</td>
<td>4 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>208</td>
<td>M</td>
<td>22</td>
<td>Sport: Football (Collegiate)</td>
<td>0</td>
<td>7 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>209</td>
<td>M</td>
<td>17</td>
<td>Sport: Football (High School)</td>
<td>3</td>
<td>32 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>210</td>
<td>M</td>
<td>16</td>
<td>Sport: Football (High School)</td>
<td>0</td>
<td>33 days</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>211</td>
<td>M</td>
<td>22</td>
<td>Sport: Football (Collegiate)</td>
<td>1</td>
<td>2 days</td>
<td>Dolan (2013)</td>
</tr>
<tr>
<td>212</td>
<td>F</td>
<td>18</td>
<td>Sport: Basketball (Collegiate)</td>
<td>0</td>
<td>1 day</td>
<td>Dolan (2013)</td>
</tr>
<tr>
<td>213</td>
<td>F</td>
<td>19</td>
<td>Sport: Basketball (Collegiate)</td>
<td>1</td>
<td>6 hours</td>
<td>Dolan (2013)</td>
</tr>
<tr>
<td>214</td>
<td>M</td>
<td>18</td>
<td>Sport: Ice Hockey (Semi-Professional)</td>
<td>3</td>
<td>4 days</td>
<td>Dolan (2013)</td>
</tr>
<tr>
<td>215</td>
<td>M</td>
<td>19</td>
<td>Sport: Ice Hockey (Semi-Professional)</td>
<td>3</td>
<td>12 days</td>
<td>Dolan (2013)</td>
</tr>
<tr>
<td>216</td>
<td>F</td>
<td>19</td>
<td>Sport: Cheerleading (Collegiate)</td>
<td>0</td>
<td>6 days</td>
<td>Dolan (2013)</td>
</tr>
<tr>
<td>217</td>
<td>M</td>
<td>19</td>
<td>Sport: Ice Hockey (Semi-Professional)</td>
<td>0</td>
<td>3 days</td>
<td>Dolan (2013)</td>
</tr>
<tr>
<td>218</td>
<td>F</td>
<td>19</td>
<td>Sport: Dance (Collegiate)</td>
<td>0</td>
<td>2 days</td>
<td>Dolan (2013)</td>
</tr>
</tbody>
</table>

The control group consisted of 18 individuals, closely age-matched with the SRC group, who had not reported a concussion within the past year. Inclusion criteria for the control group were the following: (a) ages 13-40; (b) no hearing loss; (c) no history of drug or alcohol abuse; (d) no previous history of psychiatric illnesses; (e) no previous history of a learning disability; (f) no history of seizures, brain tumors, etc.; (g) English as a dominant language. Table 3.2 displays the demographic information for the control group. Table 3.3 summarizes the demographic information for both groups.
Table 3.2 Demographic information for the control group.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age</th>
<th>Sport</th>
<th>Medical History</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>F</td>
<td>21</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>102</td>
<td>F</td>
<td>23</td>
<td>Mountain Biking</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>103</td>
<td>F</td>
<td>21</td>
<td>Track &amp; field</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>104</td>
<td>M</td>
<td>20</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>105</td>
<td>F</td>
<td>17</td>
<td>Basketball</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>106</td>
<td>M</td>
<td>23</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>107</td>
<td>F</td>
<td>20</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>108</td>
<td>M</td>
<td>18</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>109</td>
<td>F</td>
<td>22</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>110</td>
<td>F</td>
<td>21</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>111</td>
<td>M</td>
<td>23</td>
<td>Baseball</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>112</td>
<td>F</td>
<td>16</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>113</td>
<td>F</td>
<td>18</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>114</td>
<td>M</td>
<td>13</td>
<td>Soccer</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>115</td>
<td>M</td>
<td>22</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>116</td>
<td>M</td>
<td>23</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>117</td>
<td>F</td>
<td>18</td>
<td>Non-Athlete</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
<tr>
<td>118</td>
<td>F</td>
<td>15</td>
<td>Track &amp; field</td>
<td>None</td>
<td>Hewitt (2015)</td>
</tr>
</tbody>
</table>

Table 3.3 Summary of demographic information for both groups.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Control Group</th>
<th>SRC Group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>19.66 (± 3.03)</td>
<td>18.78 (± 2.37)</td>
</tr>
<tr>
<td><strong>Years of Ed.</strong></td>
<td>12.83 (± 2.85)</td>
<td>12.28 (± 2.44)</td>
</tr>
<tr>
<td><strong>Height, in.</strong></td>
<td>66.72 (± 4.40)</td>
<td>66.83 (± 4.48)</td>
</tr>
<tr>
<td><strong>Weight, lbs.</strong></td>
<td>154.61 (± 43.43)</td>
<td>159.39 (± 47.55)</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td>7 Males, 11 Females</td>
<td>11 Males, 7 Females</td>
</tr>
<tr>
<td><strong>Handedness:</strong></td>
<td>R = 18; L = 0; A = 0</td>
<td>R = 15; L = 2; A = 1</td>
</tr>
</tbody>
</table>

Standard deviations are represented in parenthesis.
3.2 Participant Recruitment

Participants in the SRC group were recruited from the University of Texas at El Paso’s Concussion Management Clinic and Sports Management/ Medicine. All individuals were diagnosed with a concussion by the athletic trainer, and/or a physician prior to being referred to the clinic. Upon completion of the protocol, participants received a $25 Wal-Mart gift card funded by a concussion grant.

Participants in the control group were recruited from various programs in the Department of Rehabilitation Sciences, at the University of Texas at El Paso (UTEP). Adolescents were recruited through on-campus students- mainly younger siblings. Upon completion of the protocol, participants received a $10 gift card funded by a concussion grant.

3.3 Setting

The current study utilized both, the UTEP Speech, Hearing and Language Clinic and the Concussion Management Clinic (CMC) for testing. The Speech Hearing and Language Clinic rooms were utilized to meet with the participants, orally explain the procedures, fill out initial participant medical history form, consent forms, and to disseminate recommendations (for individuals who suffered a concussion). Individuals were also made aware of their right to withdraw from the study at any time. Participants were then taken to the clinic to carry out the study procedures.

Hearing screenings and acoustic recordings were obtained in a soundproof booth to mirror standard test administration conditions and for consistent reliability.
3.4 Procedure

Consent forms and explanation of procedures took place before any testing began. The process began with the administration of the following two procedures: (a) medical history questionnaire and (b) hearing screening. If any of the above criteria were not met, participants were automatically dismissed. The SRC group and the control group both underwent a CMC standard protocol/battery, which will be described in detail in this chapter. However, for the purposes of this study only the motor speech and the motor limb task data and outcomes will be reported in the results section.

Upon confirmation of eligibility, informal and formal, assessments were administered to each group. The protocol consisted of a: (c) Post Injury interview- for individuals in the SRC group only; (d) *Romberg Test; (e) Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT); (f) Handedness Questionnaire; (g) Pitt and Post Traumatic Stress Disorder questionnaire; (h) 3-D shape copying task; (i) Verbal Fluency Assessment; (j) Nintendo-Wii Basic Balance assessment; (k) Oral Diadochokinesis (DDK) tasks; (l) Sentence Intelligibility Test (SIT); and (m) the motor limb tasks. Administration of the entire protocol was obtained during the first initial visit. The protocol ranged from one and a half to two hours.

Two levels of randomization were utilized. In order to account for fatigue, the protocol was randomized. Tasks were administered in the same order as stated above; however, (k) DDK, (l) SIT, and (m) motor limb tasks were administered either at the beginning or at the end of the protocol.

An additional level of randomization was considered within the DDK tasks, and four conditions were created. Two conditions in the beginning: eliciting SMRs first and then AMRs

---

1*Represent tasks that were only administered to the individuals in the SRC group.
2Represents were the randomization of tasks (k)-(m) would commence.
or AMRs first and then SMRs; two conditions at the end: eliciting SMRs first and then AMRs or AMRs first and then SMRs. Therefore, DDK tasks were either given at the beginning or end of the protocol and 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 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 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, on either ear, they were eliminated and a referral was made to their primary doctor. For the current study, all participants in the SRC group met this requirement; 3 participants in the control group were disqualified.

Post Injury Interview

The SRC group underwent a post-injury interview with the examiner to gather detailed information regarding the current concussion and any previous concussions. The examiner recorded all of responses in the post-injury form, and also obtained 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, recall of events: pre and post-concussion. Additionally, the 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 (0-6: one being the least severe and 6 the most severe) (adopted from ImPACT, 2012).
Romberg Test

The Romberg Test, a neurological test for balance, was administered only to individuals in the SRC group. According to Khasnis & Gokula (2003) an individual with proprioception dysfunction, which is common among individuals after a concussion, can still mask the dysfunction using other senses such as visual and vestibular feedback. In this task, the participant faced a certain direction and was instructed to close their eyes, stand up straight, feet together, and arms forward (at chest and shoulder level). The examiner observed their balance and then slightly pushed the participant forward and then again from the side. After each push, the examiner re-evaluated the patient’s posture for signs of swaying or any failure to maintain balance. If no swaying or imbalance was observed, then the Romberg test was considered negative; whereas, a significant imbalance, especially when closing the eyes, was considered positive (Khasnis & Gokula, 2003).

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

The Immediate Post-Concussion Assessment and Cognitive Testing exam is a computerized and standardized neurocognitive assessment that takes approximately 20-25 minutes to administer. The ImPACT (2012) test is divided into three major parts: part one, gathers participant demographic information; part two, administers the test modules; part three, ranks post-concussion symptoms on a Likert scale of 0-6 and derives a total symptom score. The ImPACT (2012) generates data based on an individual’s performance on six modules: Word Memory, Design Memory, X’s and O’s, Symbol Match, Color Match, and Three Letters. The test yields five composite scores: verbal memory composite, visual memory composite, visual motor speed composite, reaction time composite, impulse control composite, along with a total symptom score, and cognitive efficiency index. The cognitive efficiency index reports the
athlete’s performance between speed and memory for the Symbol Match subtest (ImPACT Clinical Interpretive Manual, 2007-2012). All of these indicators have been demonstrated to be sensitive to a concussion (ImPACT Clinical Interpretive Manual, 2007-2012).

Both groups were administered the ImPACT test. For the control group, the ImPACT test scores were compared to normative data provided in the manual. Additionally, their information was filed for future baseline reference in case they suffer a concussion. ImPACT test performances, for the SRC group, were compared to the individual’s baseline where appropriate. If no baseline information was available, the patient’s performance was measured against the normative data provided in the manual.

Handedness Questionnaire

Both groups filled out a handedness questionnaire. The questionnaire revolved around specific tasks. It required the 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 ultimately 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 administered to both groups. The Pitt questionnaire required the individual to answer questions, in a written format, such as: the current date, month, year, day of the week, location, etc. The questionnaire was administered to highlight any underlying cognition or memory problems they may be experiencing as a result of their concussion. Additionally, the PTSD questionnaire was administered to detect and check for any stress producing ailments including flashbacks, nightmare, or negative feelings correlated with their 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, fluctuating in complexity, to the best of their ability. If the baseline was originally obtained, a comparison was made between both drawings. Otherwise, a comparison was made during their follow-up appointment/drawing. 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. The assessment required individuals to generate as many words, within a one-minute time constraint, beginning with a certain letter and/or name of a specified (animal) category (Tombaugh, Kozak, & Rees, 1999). According to Martins and colleagues (2007), verbal fluency tasks are used to assess executive functions such as: planning a search strategy, maintaining instructions and retrieving items on line, inhibiting repetitions, automatic responses, and violations of the rules, and alternating search strategies. The verbal fluency task consisted of both phonemic and semantic elicitations. In the phonemic fluency elicitation, the participants were asked to produce as many words beginning with the following letters: S, F, A, J, R. For the semantic elicitation, the participants were asked to generate the name of as many animals within the same, one-minute time frame. The examiner recorded the words being produced and tallied the correct number of responses, excluding: any proper names, repetitions, the same word with a different suffix, or wrong items. The adequate percentile was derived using normative data from the Tombaugh, Kozak, & Rees (1999) study, in order to compare both groups. However, the normative data did not include information for individuals under the age of 16.
Both groups participated in the Nintendo Wii Basic Balance Test. The test was administered to obtain a measure of the participants’ balance skills. During setup, a Nintendo Wii Balance Board was placed six feet from the television screen. The participant was asked to step on the board with both feet apart. The examiner explained the procedure to the participant and demonstrated the movement required for the activity. Participants were allotted 30 seconds to complete five basic balancing tasks. Upon completion, scores were recorded for each participant.

3.5 Speech Tasks

3.5.1 Oral Diadochokinesis Tasks

The Computerized Speech Lab (CSL) model 4500 by Kay elemetrics, with a sampling Hz of 11025, was used to record the DDK tasks for both groups. Inside a sound-treated booth, participants sat across from the examiner. A condenser microphone (model C420) was positioned approximately one inch from the center of the mouth. The examiner orally read the standardized instructions and modeled the desired productions. Each participant was given an opportunity to practice the sequence- not exceeding three trials; this assured every participant completely understood the task before proceeding. For individuals producing inaccurate DDK productions, such as a repetition of a consonant in either AMRs or SMRs, they were asked to repeat the sequence until an accurate production was obtained.

Alternating Motion Rates

In eliciting the alternating motion rates (AMR), participants were instructed to take a deep breath and individually repeat the monosyllables /puh/, /tuh/, /kuh/ as fast and as accurate as possible. Therefore, the participant took a deep breath and repeated the /puh/ syllable, as fast
and as accurately as possible. Once the examiner was sure to have recorded 12 syllables, the participant was asked to stop. Participants did not have to complete any of these tasks under a time constraint, however, a fixed number of ten syllables were measured to calculate mean syllable duration and total mean duration using the CSL (see acoustic analysis down for explanation of analysis). The same process was repeated when eliciting the /tuh/ and /kuh/ syllables.

**Sequential Motion Rates**

In eliciting the sequential motion rates (SMR), the participant was instructed to take a deep breath and produce the trisyllable: /puhtuhkuh/ as quickly and as accurately as possible. The examiner recorded twelve sequences for this task, and then asked the participant to stop at the end of the 12\textsuperscript{th} sequence. If any misarticulation was noted during the recording, the participant was asked to produce the sequence again. Participants did not have to complete any of these tasks under a time constraint, however, 10/12 tri-syllables were measured for mean tri-syllable duration and total mean duration using the CSL (see acoustic analysis below for explanation of analysis).

### 3.5.2 Sentence Intelligibility Test (SIT)

The SIT is a computerized and standardized assessment that randomly selects 11 sentences (varying in length from 5-15 words) for the examiner to administer to each participant (Yorkston, Beukelman, and Hakel, 1996). Standardized instructions were read to the participants, and the test was administered according to the manual instructions. All sentences were recorded using a Marantz, PMD670, digital compact flash portable recorder. During the recording if the participants displayed difficulty remembering the sentence, the examiner allowed the participant
to re-record the sentence since speech rate was the area of focus rather than information recall. The participants were allowed to practice before recording again.

3.6 Motor Limb Tasks

3.6.1 Finger Repetition Task

Both groups were administered the finger repetition task. Each participant was seated in a chair across from the examiner. A Mac Book Pro computer was placed on top of a computer table, next to the examiner facing the participant directly and ready to begin recording. The examiner read the standardized instructions, directing the participant to perform a finger repetition task. The task required the participant to alternate their fingers, beginning with contact of the thumb to index finger followed by thumb to middle finger and finally thumb to ring finger, in a sequential motion. Each participant was asked to focus on speed and accuracy. Each participant was then given the opportunity to practice two productions of the finger repetition task – with their dominant hand - to ensure criterion was explicitly understood before commencing. When ready to begin, the examiner began the video recording using the Photo Booth camera, version 7.0. A total of twelve finger repetitions were recorded and since only ten finger repetitions were warranted, the ten finger repetitions were later timed using video playback (see finger repetition analysis below for explanation).

3.6.2 Movement Execution Initiation Time Task

Both groups participated in the movement execution initiation time task. Each participant was given a handheld digital stopwatch and was instructed to start and stop the stopwatch with their dominant hand: using the thumb to start and index finger to stop the time, as quickly and accurately as possible. Each participant repeated this task three separate times. The scores for all three trials were averaged to obtain one movement execution initiation time.
3.7 Analysis

3.7.1 Acoustic Analysis

The Computerized Speech Lab (CSL), model 4500, by Kay Elemetrics was also utilized to analyze and calculate the DDK duration times. Again, because there were a fixed number of syllable occurrences elicited for each DDK task, a rate will not be reported rather the mean syllable duration and total mean duration will be reported instead.

For each analysis, a combination of the waveform and spectrogram displays were simultaneously aligned on the CSL screen, sized to the same window size, and the cursors were linked. The waveform display was the primary source of analysis along with audio perception. To ensure consistency in analyzing the onset of the initial syllable and the offset of the final syllable, a 0.3 second window expansion was utilized both at the beginning and again at the end, to accurately measure all of the DDK sequences (see illustration 3.1 and 3.2). The beginning cursor was manually placed where the waveform came off of the baseline and the end cursor was manually placed where the waveform flat lined back to the baseline. However, if there was any obscurity in identifying the onset and/or offset of a syllable, the spectrogram display was utilized as a secondary form of analysis to accurately define the onset or offset of the syllable. Only ten productions were measured for each DDK task. Out of the twelve syllable productions, the beginning syllable of each trial was dismissed and measurements began with the 2nd production, followed by the subsequent syllables, up to the 11th production.

Illustration 3.1 Shows the 0.3 second expansion to measure the onset of a tri-syllable sequence.
Illustration 3.2 Shows the 0.3 second expansion to measure the onset of a tri-syllable sequence.

For the SMR task, the cursors were manually placed on the second onset of /puh/ syllable and at the end of the final offset of the /kuh/ syllable of the 11th syllable sequence. A 0.3 second window expansion (the third tick mark on the ruler of the bottom of the screen) was used to measure the onset and offset of the entire sequence. Once the beginning and end cursors were placed, the CSL calculated the total time, for all ten /puhtuhkuh/ tri-syllable sequences with gap durations, in seconds. Additionally, each /puhtuhkuh/ sequence was measured one at a time, using an 0.8 second window expansion to measure the onset and offset of each tri-syllable sequence for the SRC group and a .05 second window expansion was used for the control group. Cursors were manually placed at the beginning and end of each /puhtuhkuh/ sequence (see Illustration 3.3), and the CSL calculated the total duration time for each tri-syllable sequence.

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

In the AMR task, the cursors were manually placed on the onset of the 2\textsuperscript{nd} production of the /puh/ syllable and at the offset of the final, 11\textsuperscript{th} production, of the /puh/ syllable. A 0.3 second window expansion was used to measure the onset and offset of the entire sequence. Cursors were manually placed at the onset and offset of each /puh/ syllable to obtain the syllable duration time, without intersyllable gap durations. For each analysis, one to three /puh/ waveforms were analyzed at a time (see Illustration 3.4), using a 0.5 second window expansion for the SRC group and a 0.3 second window expansion for the control group. The same analysis procedures were repeated to obtain the measurements of the other two syllables: /tuh/ and /kuh/.

![Illustration 3.4](image)

**Illustration 3.4** Acoustic analysis showing blue cursors at the onset and offset of the /puh/ syllable.

Mean syllable duration and total mean duration were calculated, with and without intersyllable gap durations, for comparison between the groups. Additionally, with the measurements of the individual AMR syllables, intersyllable gap duration times were also obtained and calculated to be compared across groups.
3.7.2 Speech Rate and Intelligibility Analysis

In order for a transcription to be valid for the SIT, the examiner is not allowed to transcribe the sentences due to prior sentence exposure. The individual assigned to judge the sentences, then, cannot have any foreknowledge of the content of the sentences (Yorkston, Beukelman, and Hakel, 1996). Therefore, a trained graduate research assistant used audio playback to examine and transcribe each sentence individually. Sentences were then carefully measured for time duration using audio playback simultaneously with the timer provided in the SIT software. Once the sentence transcription and timing was completed, the SIT software automatically calculated the intelligibility, speech rates (IWPM and WPM), and CER for each participant.

In order to calculate the syllables per minute, an individual report consisting of all of the sentences produced by each participant was printed and analyzed individually. The examiner manually counted each syllable in each sentence and then tallied the number of syllables produced by the participant. The total number of syllables were then divided by the total duration time and then multiplied by 60 to get the syllables per minute.

3.7.3 Limb Task Analysis

In the finger repetition task, a visual analysis using QuickTime player, version 10.4, was used. The examiner opened the participant video and once opened selected the edit option, and then trim. This option allowed 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 moved the cursor at the bottom along the video trimmings, the finger repetitions were shown in the enlarged screen in slow motion. This allowed the examiner to accurately calculate the duration time for the finger repetitions using time provided by the program. Only
ten finger repetition sequences, of the twelve obtained, were measured in order to ensure that each participant was timed accurately. The initial time began with the contact of 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 movement execution initiation time task, time is recorded in real-time since 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 later averaged to provide one total movement execution initiation time.

3.8 Reliability

Standardized instructions were created and administered before each motor speech and motor limb task to warrant consistency. 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>
<thead>
<tr>
<th>DDK TASKS</th>
<th>SRC</th>
<th>CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR W/GAP</td>
<td>.996</td>
<td>.999</td>
</tr>
<tr>
<td>SMR W/O GAP</td>
<td>.931</td>
<td>.982</td>
</tr>
<tr>
<td>PUH W/GAP</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>PUHW/O GAP</td>
<td>.999</td>
<td>.998</td>
</tr>
<tr>
<td>TUH W/GAP</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>TUHW/O GAP</td>
<td>.997</td>
<td>.990</td>
</tr>
<tr>
<td>KUH W/GAP</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>KUH W/O GAP</td>
<td>.998</td>
<td>.998</td>
</tr>
</tbody>
</table>

80% of the finger repetition tasks, for the control group and SRC group, were randomly selected to be re-computed. 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 0.912 for the control group and 0.954 for the SRC group between raters.

A trained research assistant transcribed all of the SIT samples to determine consistency in IWPM. For reliability, a second trained research assistant transcribe 25% of the samples for the SRC and control group. An ICC showed an inter-rater agreement of 0.930 for the control group and 0.984 for the SRC group between raters.

3.9 Data Analysis

A Shapiro-Wilk test of normality was calculated to determine if the groups were normally distributed. For the SRC group, certain tasks were not normally distributed. Therefore, an independent-samples t-test \((\alpha = 0.05)\) was used to examine group differences since this test can bypass the assumption of normal distribution (Cronk, 2012). The p-value was not adjusted for multiple serial \(t\)-tests. A one-way ANOVA \((\alpha = 0.05)\) was also used to determine group differences in some of the speech tasks. However, because some of the groups did lack normal distribution, a non-parametric test: Mann-Whitney-U was calculated for all tasks.

The first research question set out to examine group differences in DDK mean syllable duration between the groups. The independent variable was the SRC group and the control group. The dependent variables were the DDK times. The third research question set out to analyze the differences in total mean duration for the motor limb tasks between the groups. The independent variable was the SRC and control group, and the dependent variables were the finger repetition and movement execution initiation times. The fourth research question examined the differences in speech rate between the groups. The independent variable was the SRC and the control group, and the dependent variable was the IWPM.
A Spearman correlation coefficient was used to examine the relationship between speech and motor limb times and within speech tasks. The second research question, which set out to see if any correlation existed in total mean duration between the DDK and the motor limb tasks, across groups, was answered by using a Spearman correlation coefficient. This correlation was of interest because of the anatomical similarities between the finger repetition sequence and the SMR task. The SMR task required the individual to articulate, using their tongue in a specific sequence: from lips to the tongue tip, and then the tongue dorsum when producing the /puhtuhkuh/ sequence (Ziegler, 2002). Likewise, the finger repetition task required the individual to move their first three fingers (index, middle, and ring) in a repetitive sequence as well. Furthermore, the fifth research question investigated if any correlation existed between DDK times and IWPM.

Additionally, a multiple linear regression was calculated to predict the participants’ IWPM, SMRs and AMR: /puh/ syllable based on their total symptom scores (TSS), history of concussion (HOC) and post-concussion hours (PCH).
CHAPTER IV

RESULTS

This chapter delineates the findings obtained by the retrospective data from Dolan’s (2013) SRC group, concurrently with the current SRC group data for the tasks replicated. Furthermore, the experimental findings for the additional tasks added, to the current study, will only include the current SRC group.

4.1 Oral Diadochokinesis: Mean Syllable Duration

The first research question sought to examine the differences in DDK mean syllable duration between the SRC group and the control group. Results demonstrated slower DDK mean syllable duration in the SRC group in comparison to the control group. An independent-samples t-test revealed a statistically significant difference in DDK mean syllable duration across groups: SMRs \( t(34) = -6.827, p < .001 \), AMR /puh/ \( t(26) = -5.566, p < .001 \), AMR /tuh/ \( t(26) = -4.760, p < .001 \), and AMR /kuh/ \( t(26) = -4.978, p < .001 \).

The SMR mean tri-syllable duration for the SRC group was 482 milliseconds ± 80.17 in comparison to 341 milliseconds ± 34.93 for the control group. A difference of more than 100 milliseconds was noted between the groups.

The AMR mean syllable duration, in milliseconds, for each syllable, were the following: /puh/- 146 milliseconds ± 27.32 exhibited for the SRC group in comparison to 103 milliseconds ± 14.25 for the control group; /tuh/- 183 milliseconds ± 51.11 for the SRC group in comparison to 119 milliseconds ± 20.79 for the control group; /kuh/- 189 milliseconds ± 46.55 in the SRC group in comparison to 125 milliseconds ± 22.33 for the control group. Figure 4.1 displays all DDK mean syllable duration times.
4.2 DDK Mean Total Duration

Results demonstrate overall slower mean duration across all DDK tasks, with and without intersyllable gap durations, in the SRC group in comparison to the control group. An independent-samples $t$-test demonstrated a statistically significant difference, between groups, for total mean duration for SMRs, with gap durations, [$t(34) = -4.957, p < .001$]. The total mean duration for SMRs in the SRC group was 5.27 seconds ± 0.93 while the total mean duration for SMRs in the control group was 4.06 seconds ± 0.46.

Additionally, a statistically significant difference was found for the SMRs, without gap durations, [$t(34) = -6.827, p < .001$] between groups. The overall mean duration for SMRs for the SRC group was 4.82 seconds ± 0.80 while the overall mean duration for the SMRs for the control group was 3.41 seconds ± 0.35.

In analyzing AMRs, with intersyllable gap durations, an independent-samples $t$-test revealed a statistically significant difference for all three syllables: /puh/ [$t(26) = -6.478, p <
.001], /tuh/ [t(26) = -4.338, p < .001], and /kuh/ [t(26) = -4.213, p < .001] between groups. The overall mean duration for the /puh/ syllable was 2.06 seconds ± 0.25 for the SRC group in comparison to 1.55 seconds ± 0.16 for the control group. The overall mean duration for the /tuh/ syllable was 2.36 seconds ± 0.64 for the SRC group in comparison to 1.63 seconds ± 0.24 for the control group. The overall mean duration for the /kuh/ syllable was 2.42 seconds ± 0.61 for the SRC group in comparison to 1.71 seconds ± 0.29 for the control group.

In analyzing the AMRs, without intersyllable gap durations, an independent-samples t-test revealed a statistically significant difference for all three syllables: /puh/ [t(26) = -5.566, p < .001], /tuh/ [t(26) = -4.760, p < .001], and /kuh/ [t(26) = -4.978, p < .001], between groups. The overall mean duration for the /puh/ syllable was 1.46 seconds ± 0.27 for the SRC group in comparison to 1.03 seconds ± 0.14 for the control group. The overall mean duration for the /tuh/ syllable was 1.83 seconds ± 0.51 for the SRC group in comparison to 1.19 seconds ± 0.21 for the control group. The overall mean duration for the /kuh/ syllable was 1.89 seconds ± 0.47 for the SRC group in comparison to 1.25 seconds ± 0.22 for the control group.

Therefore, the SRC group exhibited significantly slower total mean duration, for the SMRs and AMRs, with and without intersyllable gap durations, compared to the control group. 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) and Hewitt (2015) data. Asterisk shows significance at the 0.01 or less level.

**Figure 4.3** AMR total mean duration, with and without intersyllable gap durations, across groups. Group comparisons include only Hewitt (2015) data. Asterisk shows significance at the 0.01 or less level.
4.3 DDK Intersyllable Gap Durations

In analyzing the mean intersyllable gap durations, an independent-samples $t$-test showed that there was no statistically significant difference between the groups. The following are the results for the DDK mean intersyllable gap durations: SMR [$t(26) = -0.747, p > .05$], AMR: /puh/ intersyllable gap duration [$t(26) = -1.934, p > .05$], AMR: /tuh/ intersyllable gap duration [$t(26) = -1.522, p > .05$] and AMR: /kuh/ intersyllable gap duration [$t(26) = -1.478, p > .05$].

The mean intersyllable gap duration time for SMRs in the SRC group was 78 milliseconds ± 21.15 in comparison to 72 milliseconds ± 19.29 for the control group. The mean intersyllable gap duration time for the AMR: /puh/ sequence was 67 milliseconds ± 10.99 in comparison to 58 milliseconds ± 11.16 for the control group. The mean intersyllable gap duration time for the AMR: /tuh/ was 59 milliseconds ± 20.06 in comparison to 49 milliseconds ± 11.61 for the control group. The mean intersyllable gap duration time for the AMR: /kuh/ was 60 milliseconds ± 21.28 in comparison to 51 milliseconds ± 11.58 for the control group. See Figure 4.4 for a summary of mean intersyllable gap duration times.

![Mean Intersyllable Gap Durations ± 1 SD](image)

*Figure 4.4* Mean intersyllable gap duration across groups; Hewitt (2015) data only.
4.4 Correlation Between DDK and Motor Limb Tasks

The second research question sought to investigate the correlation between the DDK total duration times, without intersyllable gap durations and the motor limb tasks between groups.

A Spearman rho correlation coefficient was calculated for the relationship between DDK and motor limb tasks across groups. An extremely weak relationship that was not significant was found between groups across DDK and motor limb tasks. See Table 4.1 for correlation results for DDKs and motor limb tasks.

Table 4.1 Spearman correlation coefficient: mean total duration for speech and limb tasks across groups.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>SRC Group</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMRs and Finger Repetition</td>
<td>([r (16)= .055, p = .829])</td>
<td>([r (16)= -.035 , p = .890])</td>
</tr>
<tr>
<td>SMRs and Movmt. Ex. Initiation</td>
<td>([r (16)= -.188 p = .454])</td>
<td>([r (16)= .197, p = .434])</td>
</tr>
<tr>
<td>AMR: /puh/ and Finger Repetition</td>
<td>([r (8)= -.006, p = .987])</td>
<td>([r (16)= -.093 , p = .714])</td>
</tr>
<tr>
<td>AMR: /puh/ and Movmt. Ex. Initiation</td>
<td>([r (8)= -.322, p = .364])</td>
<td>([r (16)= -.220, p = .381])</td>
</tr>
<tr>
<td>AMR: /tuh/ and Finger Repetition</td>
<td>([r (8)= -.207, p = .567])</td>
<td>([r (16)= -.207, p=.411])</td>
</tr>
<tr>
<td>AMR: /tuh/ and Movmt. Ex. Initiation</td>
<td>([r (8)= -.232, p = .519])</td>
<td>([r (16)= .172, p=.495])</td>
</tr>
<tr>
<td>AMR: /kuh/ and Finger Repetition</td>
<td>([r (8)= .055, p = .881])</td>
<td>([r (16)= -.165 , p=.512])</td>
</tr>
<tr>
<td>AMR: /kuh/ and Movmt. Ex. Initiation</td>
<td>([r (8)= -.152, p = .675])</td>
<td>([r (16)= .203, p=.419])</td>
</tr>
</tbody>
</table>

Note: Group comparisons for SMRs and limb tasks include Dolan (2013) data and Hewitt (2015) data only. Group comparisons for AMRs and limb tasks include Hewitt (2015) data only.

4.5 Motor Limb Tasks Between Groups

An independent-samples \(t\)-test was calculated to answer the third research question, which investigated the differences in motor limb tasks between groups. The SRC group showed slower motor limb movements in comparison to the control group.

A statistically significant difference was found, between groups, in the finger repetition task \([t(34) = -2.124, p < .05]\). The total mean duration for the SRC group was 8.01 seconds ±
1.66 and the total mean duration for the control group was 6.86 seconds ± 1.60. See Figure 4.5 for the finger repetition results.

For movement execution initiation time task, there was a statistically significant difference between the groups \([t(34) = -2.160, p < .05]\). The total mean duration time for the SRC is 172.44 milliseconds ± 136.97 for the SRC group in comparison to 101.11 milliseconds ± 29.68 for the control. See Figure 4.6 for mean movement execution initiation time tasks results.

![Mean Finger Repetition Duration ± 1 SD](image)

**Figure 4.5** Finger repetition duration in seconds across groups. Group comparisons include Dolan (2013) and Hewitt (2015) data. Asterisk shows significance at the 0.05 or less level.
Figure 4.6 Mean movement execution initiation time task across groups. Group comparisons include Dolan (2013) and Hewitt (2015) data. Asterisk shows significance at the 0.05 or less level.

4.6 Speech Rates Between Groups

The fourth research question investigated the difference in speech rate between the SRC group and the control group. A one-way ANOVA revealed no statistically significant difference between the groups in WPM, IWPM, syllables per minute (SPM) or CER. Although no significant difference was present, results did show slower speech rates for the SRC group in comparison to the control group.

There was no statistically significant difference found in total words per minute [F(1,26) = 3.193, p > .05] between the groups. The total mean duration in total words per minute for the SRC group was 191.10 ± 23.22 in comparison to 210.22 words per minute ± 28.98 for the control group.
There was no statistically significant difference found in SPM \([F(1,26) = 3.550, p > .05]\). The total mean duration in SPM for the SRC group was 259.35 ± 24.25 in comparison to 284.24 ± 37.49 for the control group.

For IWPM, there was no statistically significant difference \([F(1,26) = 3.411, p > .05]\) between the groups. The total mean duration for the SRC group was 187.09 intelligible words per minute ± 22.71 in comparison to 206.94 intelligible words per minute ± 29.38 for the control group. Figure 4.7 summarizes the speech rate results across groups.

There was no statistically significant difference found in Communication Efficiency Ratio (CER) between the groups \([F(1,26) = 3.558, p > .05]\). The total mean ratio for the CER for the SRC group was 0.98 ± 0.12 in comparison to 1.09 ± 0.15 for the control group. Figure 4.8 displays the CER results across groups.

![Mean Speech Rate ± 1 SD](image)

**Figure 4.7** Speech rate results across groups. Group comparisons include Hewitt (2015) data only.
Figure 4.8 Summary of communication efficiency ratio across groups. Group comparisons include Hewitt (2015) data only.

4.7 Correlation Between DDK Mean Syllable Duration Times and Speech Rate

The fifth research question sought to investigate the level of relationship between the DDK mean syllable duration in milliseconds, with gap durations, and the speech rate tasks between groups and a Spearman $\rho$ correlation coefficient was used to answer this question.

A Spearman correlation coefficient revealed a weak relationship for SMRs and all AMRs of the SRC group. Similar results were found for the control group, with the exception of the AMR: /kuh/ syllable. A moderate negative relationship was found indicating a significant relationship between the AMR /kuh/ mean syllable duration and the IWPM and SPM. Table 4.2 displays the results for both the SRC and control groups.

Table 4.2 Spearman Correlation: DDK mean syllable duration (w/gap) and speech rate across groups.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>SRC Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR and IWPM</td>
<td>$[r (8)=-.267, p = .455]$</td>
<td>$[r (16)=-.040, p = .874]$</td>
</tr>
<tr>
<td>SMR and SPM</td>
<td>$[r (8)=.018, p = .960]$</td>
<td>$[r (16)=-.135, p = .593]$</td>
</tr>
<tr>
<td>AMR: /puh/ and IWPM</td>
<td>[ r (8) = .382, p = .276 ]</td>
<td>[ r (16) = -.448, p = .063 ]</td>
</tr>
<tr>
<td>AMR: /puh/ and SPM</td>
<td>[ r (8) = .333, p = .347 ]</td>
<td>[ r (16) = -.319, p = .196 ]</td>
</tr>
<tr>
<td>AMR: /tuh/ and IWPM</td>
<td>[ r (8) = .139, p = .701 ]</td>
<td>[ r (16) = -.233, p = .351 ]</td>
</tr>
<tr>
<td>AMR: /tuh/ and SPM</td>
<td>[ r (8) = .055, p = .881 ]</td>
<td>[ r (16) = -.143, p = .573 ]</td>
</tr>
<tr>
<td>AMR: /kuh/ and IWPM</td>
<td>[ r (8) = .267, p = .455 ]</td>
<td>[ \rho (16) = -.643, p = .004 ] *</td>
</tr>
<tr>
<td>AMR: /kuh/ and SPM</td>
<td>[ r (8) = .152, p = .675 ]</td>
<td>[ \rho (16) = -.511, p = .030 ] *</td>
</tr>
</tbody>
</table>

Note: Group comparisons for SMRs and limb tasks include Dolan (2013) data and Hewitt (2015) data only. Group comparisons for AMRs and limb tasks include Hewitt (2015) data only. Asterisk shows significance at the 0.5 level.

4.8 Speech Intelligibility

An independent-samples \( t \)-test revealed no significant differences in intelligibility across the groups \( [t(26) = .652, p > .05] \). The mean intelligibility for the SRC group was 97.88 ± 1.71 in comparison to 98.29 ± 1.55 for the control group.

4.9 Multiple Linear Regression Analysis

A multiple linear regression was calculated to predict the participants’ mean IWPM, SMRs and AMR: /puh/ mean syllable duration based on their total symptom scores (TSS), history of concussion (HOC) and post-concussion hours (PCH).

A multiple linear regression was calculated to predict the participant’s IWPM based on their TSS, HOC, and PCH. The regression equation was not significant \( [F(3,6) = 3.131, p > .05] \) with an \( R^2 \) of .610. Neither TSS, HOC, or PCH are a significant predictor of IWPM.

A multiple linear regression was calculated to predict the participant’s SMR total mean duration based on their TSS, HOC, and PCH. The regression equation was not significant \( [F(3,14) = .511, p > .05] \) with an \( R^2 \) of .099. Neither TSS, HOC, or PCH are a significant predictor of SMR total mean duration.

A multiple linear regression was calculated to predict the participant’s AMR: /puh/ mean syllable duration based on their TSS, HOC, and PCH. The regression equation was not
significant \( F(3,6) = 3.721, p > .05 \) with an \( R^2 \) of .650. Neither TSS, HOC, or PCH are a significant predictor of AMR: /puh/ mean syllable duration.

### 4.10 Non-Parametric Analysis

A Mann-Whitney-U was calculated on all the tasks to verify the parametric test results. Table 4.3 displays the results.

**Table 4.3** Mann-Whitney-U results for all tasks across both groups.

<table>
<thead>
<tr>
<th>Task</th>
<th>Exact Sig. ([2^\ast(1\ \text{tailed}\ \text{sig})])</th>
</tr>
</thead>
<tbody>
<tr>
<td>/puh,tuh,kuh/ tri-syllable total mean duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/puh,tuh,kuh/ with gap duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/puh,tuh,kuh/ without gap duration</td>
<td>( P &lt; .01^* )</td>
</tr>
<tr>
<td>/puh/ mean syllable duration time</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/puh/ total mean with intersyllable gap duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/puh/ total mean without intersyllable gap duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/tuh/ mean syllable duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/tuh/ total mean with intersyllable gap duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/tuh/ total mean without intersyllable gap duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/kuh/ mean syllable duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/kuh/ with intersyllable gap duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>/kuh/ without intersyllable gap duration</td>
<td>( p &lt; .001^* )</td>
</tr>
<tr>
<td>Finger Repetition task</td>
<td>( p &gt; .05 ) (( p = .051 ))</td>
</tr>
<tr>
<td>Movement Execution Initiation Time task</td>
<td>( p &lt; .01^* )</td>
</tr>
<tr>
<td>WPM</td>
<td>( p &gt; .05 )</td>
</tr>
<tr>
<td>IWPM</td>
<td>( p &gt; .05 )</td>
</tr>
<tr>
<td>SPM</td>
<td>( p &gt; .05 )</td>
</tr>
<tr>
<td>Intelligibility</td>
<td>( p &gt; .05 )</td>
</tr>
<tr>
<td>CER</td>
<td>( p &gt; .05 )</td>
</tr>
</tbody>
</table>

Results include Dolan (2013) and Hewitt (2015) data combined only for the limb tasks and the SMRs tasks. Asterisk shows significance at the 0.5 or less level.
4.11 Comparing Adult Data Only

Due to the limited number of adolescents in both groups and the disparity of brain maturation, one final analysis was calculated to see the results, in all tasks, across adults between the groups. Due to the disparity of the groups and the small number of participants, a Mann-Whitney-U was calculated. See Table 4.4 for results.

Table 4.4 Mann-Whitney-U results for all tasks, across adults, between both groups.

<table>
<thead>
<tr>
<th>Task</th>
<th>Exact Sig. [2*(1 tailed) sig]</th>
</tr>
</thead>
<tbody>
<tr>
<td>/puh,tuh,kuh/ tri-syllable total mean duration</td>
<td>p &lt; .001*</td>
</tr>
<tr>
<td>/puh,tuh,kuh/ with gap duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/puh,tuh,kuh/ without gap duration</td>
<td>P &lt; .001*</td>
</tr>
<tr>
<td>/puh/ mean syllable duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/puh/ total mean with intersyllable gap duration</td>
<td>p &lt; .001*</td>
</tr>
<tr>
<td>/puh/ total mean without intersyllable gap duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/tuh/ mean syllable duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/tuh/ total mean with intersyllable gap duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/tuh/ total mean without intersyllable gap duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/kuh/ mean syllable duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/kuh/ with intersyllable gap duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>/kuh/ without intersyllable gap duration</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>Finger Repetition task</td>
<td>p &lt; .01*</td>
</tr>
<tr>
<td>Movement Execution Initiation Time task</td>
<td>p &lt; .001*</td>
</tr>
<tr>
<td>WPM</td>
<td>p &gt; .05</td>
</tr>
<tr>
<td>IWPM</td>
<td>p &gt; .05</td>
</tr>
<tr>
<td>SPM</td>
<td>p &lt; .05*</td>
</tr>
<tr>
<td>Intelligibility</td>
<td>p &gt; .05</td>
</tr>
<tr>
<td>CER</td>
<td>p &gt; .05</td>
</tr>
</tbody>
</table>

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

All DDK total duration times, with and without intersyllable gap durations are reported in Table 4.5 for the SRC group and Table 4.7 for the control group. DDK mean syllable duration (without intersyllable gap durations), speech rates, and the motor limb tasks have been summarized; see table 4.6 for the SRC group and table 4.8 for the control group.

**Table 4.5** DDK mean duration, with and without intersyllable gap durations for the SRC group.

<table>
<thead>
<tr>
<th>Participant</th>
<th>SMR total duration time in sec</th>
<th>/puh/ total duration time in sec</th>
<th>/tuh/ total duration time in sec</th>
<th>/kuh/ total duration time in sec</th>
<th>SMR total duration w/o intersyllable gap durations in sec</th>
<th>/puh/ total duration w/o intersyllable gap durations in sec</th>
<th>/tuh/ total duration w/o intersyllable gap durations in sec</th>
<th>/kuh/ total duration w/o intersyllable gap durations in sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
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<td>1.75</td>
<td>2.05</td>
<td>2.08</td>
<td>4.80</td>
<td>1.10</td>
<td>1.42</td>
<td>1.48</td>
</tr>
<tr>
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<td>2.13</td>
<td>2.5</td>
<td>2.45</td>
<td>4.39</td>
<td>1.46</td>
<td>1.93</td>
<td>1.91</td>
</tr>
<tr>
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<td>1.90</td>
<td>1.81</td>
<td>1.98</td>
<td>5.14</td>
<td>1.18</td>
<td>1.26</td>
<td>1.49</td>
</tr>
<tr>
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<td>2.36</td>
<td>4.06</td>
<td>3.96</td>
<td>5.74</td>
<td>1.87</td>
<td>3.10</td>
<td>2.92</td>
</tr>
<tr>
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<td>2.10</td>
<td>2.18</td>
<td>2.88</td>
<td>5.45</td>
<td>1.59</td>
<td>1.80</td>
<td>2.48</td>
</tr>
<tr>
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<td>2.37</td>
<td>2.25</td>
<td>2.14</td>
<td>3.83</td>
<td>1.69</td>
<td>1.90</td>
<td>1.71</td>
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<td>1.77</td>
<td>1.97</td>
<td>2.04</td>
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<td>1.16</td>
<td>1.56</td>
<td>1.64</td>
</tr>
<tr>
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<td>2.37</td>
<td>2.28</td>
<td>3.73</td>
<td>1.40</td>
<td>1.80</td>
<td>1.69</td>
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<tr>
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<td>2.35</td>
<td>2.46</td>
<td>2.43</td>
<td>4.35</td>
<td>1.81</td>
<td>2.06</td>
<td>1.99</td>
</tr>
<tr>
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<td>6.84</td>
<td>1.79</td>
<td>1.94</td>
<td>1.98</td>
<td>6.16</td>
<td>1.36</td>
<td>1.51</td>
<td>1.63</td>
</tr>
<tr>
<td>211</td>
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<td>N/A</td>
<td>N/A</td>
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<td>N/A</td>
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<td>N/A</td>
<td>N/A</td>
<td>3.59</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>214</td>
<td>5.63</td>
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<td>N/A</td>
<td>N/A</td>
<td>5.52</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>215</td>
<td>4.21</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>4.11</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>216</td>
<td>5.95</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5.82</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>217</td>
<td>5.80</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5.63</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>218</td>
<td>4.70</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>4.57</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Raw data include Dolan (2013) and Hewitt (2015) data combined only for the limb tasks and the SMRs tasks.

**Table 4.6** DDK mean syllable duration times, speech rates, and limb tasks for the SRC group.

<table>
<thead>
<tr>
<th>Participant</th>
<th>SMR mean duration time for trisyllable in ms</th>
<th>/puh/ mean syllable duration time in ms</th>
<th>/tuh/ mean syllable duration time in ms</th>
<th>/kuh/ mean syllable duration time in ms</th>
<th>IWPM</th>
<th>WPM</th>
<th>SPM</th>
<th>F.R. in sec.</th>
<th>MEI in ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>480</td>
<td>110</td>
<td>142</td>
<td>148</td>
<td>157.21</td>
<td>158.65</td>
<td>219.23</td>
<td>7.16</td>
<td>124</td>
</tr>
<tr>
<td>202</td>
<td>439</td>
<td>146</td>
<td>193</td>
<td>191</td>
<td>197.54</td>
<td>203.08</td>
<td>267.69</td>
<td>7.50</td>
<td>120</td>
</tr>
<tr>
<td>203</td>
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<td>126</td>
<td>149</td>
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<td>9.93</td>
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<td>310</td>
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<td>153.49</td>
<td>234.42</td>
<td>9.57</td>
<td>200</td>
</tr>
</tbody>
</table>
Note: Raw data include Dolan (2013) and Hewitt (2015) data combined only for the limb tasks and the SMRs tasks.
F.R.= Finger Repetition; MEI= Movement Execution Initiation.

Table 4.7 DDK total mean duration times, with and without intersyllable gap durations for the control group.

<table>
<thead>
<tr>
<th>Participant</th>
<th>SMR total duration time in sec</th>
<th>/puh/ total duration time in sec</th>
<th>/tuh/ total duration time in sec</th>
<th>/kuh/ total duration time in sec</th>
<th>SMR total duration w/o intersyllable gap durations in sec</th>
<th>/puh/ total duration w/o intersyllable gap durations in sec</th>
<th>/tuh/ total duration w/o intersyllable gap durations in sec</th>
<th>/kuh/ total duration w/o intersyllable gap durations in sec</th>
</tr>
</thead>
<tbody>
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<td>101</td>
<td>4.18</td>
<td>1.50</td>
<td>2.05</td>
<td>1.88</td>
<td>3.43</td>
<td>0.84</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>102</td>
<td>3.59</td>
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<td>2.99</td>
<td>1.21</td>
<td>1.29</td>
<td>1.38</td>
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<td>1.83</td>
<td>2.50</td>
<td>3.44</td>
<td>0.96</td>
<td>1.25</td>
<td>1.81</td>
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<td>1.85</td>
<td>1.47</td>
<td>1.69</td>
<td>3.50</td>
<td>1.16</td>
<td>1.08</td>
<td>1.15</td>
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<td>105</td>
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<td>1.52</td>
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<td>1.02</td>
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<td>1.12</td>
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<td>3.15</td>
<td>0.82</td>
<td>0.79</td>
<td>0.92</td>
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<td>2.06</td>
<td>3.27</td>
<td>1.15</td>
<td>1.52</td>
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<td>1.47</td>
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<td>0.99</td>
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<td>1.93</td>
<td>1.51</td>
<td>3.93</td>
<td>0.80</td>
<td>1.46</td>
<td>1.10</td>
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<td>1.87</td>
<td>1.77</td>
<td>3.36</td>
<td>1.17</td>
<td>1.40</td>
<td>1.30</td>
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<td>1.10</td>
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<td>1.05</td>
<td>0.99</td>
<td>1.14</td>
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<td>1.55</td>
<td>1.66</td>
<td>1.94</td>
<td>3.74</td>
<td>0.96</td>
<td>1.34</td>
<td>1.45</td>
</tr>
<tr>
<td>116</td>
<td>3.31</td>
<td>1.52</td>
<td>1.42</td>
<td>1.34</td>
<td>2.80</td>
<td>1.08</td>
<td>1.03</td>
<td>1.01</td>
</tr>
<tr>
<td>117</td>
<td>4.27</td>
<td>1.49</td>
<td>1.43</td>
<td>1.48</td>
<td>3.46</td>
<td>1.03</td>
<td>0.87</td>
<td>1.14</td>
</tr>
<tr>
<td>118</td>
<td>4.80</td>
<td>1.65</td>
<td>1.69</td>
<td>1.93</td>
<td>4.05</td>
<td>1.01</td>
<td>1.36</td>
<td>1.34</td>
</tr>
</tbody>
</table>
Table 4.8 DDK mean syllable duration times, speech rates, and limb tasks for the control group.

<table>
<thead>
<tr>
<th>Participant</th>
<th>SMR mean duration time for trisyllable in ms</th>
<th>/puh/ mean syllable duration time in ms</th>
<th>/tuh/ mean syllable duration time in ms</th>
<th>/kuh/ mean syllable duration time in ms</th>
<th>IWPM</th>
<th>WPM</th>
<th>SPM</th>
<th>F.R. in sec.</th>
<th>MEI in ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
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<td>84</td>
<td>134</td>
<td>134</td>
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<td>191.30</td>
<td>248.69</td>
<td>6.27</td>
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<td>195.69</td>
<td>203.08</td>
<td>260.30</td>
<td>6.50</td>
<td>60</td>
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<tr>
<td>103</td>
<td>344</td>
<td>96</td>
<td>125</td>
<td>181</td>
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Raw data include Dolan (2013) and Hewitt (2015) data combined only for the limb tasks and the SMRs tasks.
Note: F.R. = Finger Repetition; MEI = Movement Execution Initiation.
CHAPTER V
DISCUSSION

Until now, the impact and the extent of SRC effects on the speech mechanism remain uncertain. Dolan’s (2013) study was the first, to our knowledge, to research the effects of a SRC on the speech mechanism. The proposed study aimed at replicating and extending Dolan’s (2013) study, which evaluated SMRs along with motor limb movements, in collegiate athletes, post-SRC. The current study further extended Dolan’s study by increasing the sample size in both groups and adding additional components to the protocol: AMRs, intelligibility, and speech rate tasks. Additionally, this study is the first of its kind, to analyze DDK tasks and speech rate, for adolescents and adults, to determine if a mild form of dysarthria or motor slowing can be a consequence of a SRC during the acute and sub-acute phase.

5.1 DDK Tasks

In the DDK task, it was hypothesized that DDK mean syllable duration and total mean duration would be slower across SMRs and AMRs for the SRC group in comparison to the control group. The experimental findings validate the original hypothesis, since the SRC group produced slower SMRs in comparison to the control group. Furthermore, the experimental findings of this study are analogous to the TBI findings, indicating that individuals post-TBI exhibit significantly slower AMR duration in comparison to control groups (Wang, et al., 2005; Wang, et al., 2004; Ziegler, 2002; Goozee, et al., 2000).

Additionally, both Wang et al., (2005; 2004) studies measure AMR syllable duration times as well as the intersyllable gap duration times. They report a simultaneous increase in syllable duration times and intersyllable gap duration times. However, the findings of the current study did not show the same pattern. Although the SRC group displayed slightly longer mean
intersyllable gap duration times in comparison to the control group, there was no statistically significant difference found. This finding indicates that the significant difference found in DDK total duration time is a result of increased syllable length, rather than both intersyllable gap durations and syllable length. However, further research is needed to validate or reject these findings.

Additionally, the Ziegler (2002) study noted a pattern in the AMRs for almost all groups, made up of individuals following a TBI and other disorders: Apraxia of Speech (AOS), cerebellar ataxic disorders, cerebrovascular accident (CVA), closed head injury (CHI), and other non-specified disorders. Ziegler’s (2002) study reports /puh/ as the fastest syllable produced, followed by the /tuh/ syllable and then the /kuh/ syllable. The same pattern was exhibited in the current study not only in the SRC group, but in the control group as well.

The experimental findings of the DDK tasks are clinically significant because slowness exhibited equally across AMRs and SMRs is indicative of the motor speech disorder: dysarthria rather than Apraxia of Speech (Cannito, 2014). However, at this time it is not for certain that these individuals were experiencing dysarthria, but rather a motor slowing of the articulators. A more thorough speech analysis combined with acoustic analysis is needed to clearly define that it is dysarthria that these athletes are experiencing post-SRC.

5.2 Motor Limb Tasks

The current results validate the original hypothesis stating that the motor limb tasks would be slower for the SRC group in comparison to the control group. The finger repetition findings for the SRC group exhibited slower duration in comparison to the control group. The SRC group of the current study also demonstrates slower movement execution initiation times in
comparison to the control group. These results further confirm that the temporary neuronal dysfunction, following a SRC, does affect the motor limb pathways.

5.3 Speech Rate

The SRC group exhibited slower speech rates in comparison to the control group; however, there was no statistical significance found rejecting the original hypothesis. The statistical findings show that the results are approaching significance. These findings indicate that the speaking rate displayed by the SRC group is slower, and, therefore, may be plausible that the athletes might be mildly impaired, in comparison to the typical speech rate found in the Yorkston et al., (1981) study and the current control group. However, due to limited participants, further research is needed to validate these findings and to reach statistical significance.

5.4 Speech Intelligibility

The SRC group did not exhibit lower intelligibility scores in comparison to the control group. Similar findings were reported in the Cahill (2002) study, which found no significant difference in intelligibility scores between individuals post-TBI, without dysarthria (NDTBI group) and the control group.

5.5 Correlations

It was hypothesized that there would be a correlation between total mean duration of DDKs and motor limb tasks. However, no correlation was found. The Spearman correlation coefficients showed that there was a weak relationship between DDK and the motor limb overall duration between the groups.

Additionally, it was hypothesized that DDK mean syllable duration and IWPM/SPM would be highly correlated. The Spearman correlation coefficient shows that there is a weak to moderate relationship, which was not significant, between the DDK mean syllable duration and
IWPM/SPM for the SRC group. However, for the control group, there was a moderate, negative relationship found between the AMR: /kuh/ mean syllable duration and speech rate (IWPM and SPM). Therefore, indicating that as the AMR: /kuh/ mean syllable duration increases as the IWPM/SPM decreases and vise versa. A weak relationship was found between the other AMRs and IWPM/SPM.

5.6 Multiple Linear Regression

The multiple linear regression findings of the current study show that TSS, HOC, and PCH are not significant predictors of IWPM, AMR: /puh/ mean syllable duration and SMR total mean duration.

5.7 Adolescents versus Adult Recovery

Although statistical analysis could not be calculated due to the limited number of adolescents, there were differences in the time it took to initiate the return-to-play/classroom protocol. Out of the four adolescents in the SRC group, three of them presented with PCS. One out of the four adolescents took more than two months for the UTEP-CMC to initiate the return-to-play protocol; two adolescents took more than one month to begin the return-to-play protocol; and one adolescent took 17 days post-concussion in order begin the return-to-play protocol. Out of these four participants, however, two out of the three adolescents presenting with PCS, had been returned to normal activities before being evaluated in the UTEP-CMC. Both of these athletes had persistent symptoms and were tested at least 25 days post-concussion during their first visit to the UTEP-CMC. Out of the four adolescents, three had suffered previous concussions already.

In comparison to the adults, there was only one adult that took 25 days for UTEP-CMC to initiate the return-to-play protocol; three adults took between 15-20 days to begin the return-
to-play protocol; eight adults took between 7-14 days to begin the return-to-play protocol; and two adults were allowed to initiate the return-to-play protocol in less than 6 days.

Overall, adolescents took a lot longer time to begin the return-to-play protocol in comparison to the adults. The findings of the current study support much of the literature (Barr et al., 2013; McCrae, et al., 2010; Zuckerman, et al., 2012; Field, et al., 2003) suggesting that adolescents are more vulnerable to SRC impacts and are more symptomatic for longer periods of time in comparison to adults.

5.8 Clinical Implications

One of the most robust attributes of DDK tasks is their usefulness in detecting motor speech disorders by highlighting underlying motor speech impairments (Gadesmann & Miller, 2008). In this study, DDKs were analyzed acoustically, which allowed for the precise measurement of total mean duration and mean syllable duration between the groups. Although one of the adolescent athletes reported no symptoms during the time of testing, his DDK times revealed mild impairments averaging among the longest times in DDK tasks within the SRC group. Therefore, DDK tasks can be a valuable tool in the clinical setting to determine severity for all athletes since athletes may underreport their symptoms.

Perceptually in five out of the ten athletes recruited in the SRC group, the DDK tasks were useful in highlighting slow speech rate, misarticulations in both SMRs and AMRs, and a monopitch voice characteristic. However, further exploration comparing the DDK mean syllable and/or total duration time, speech rate tasks’ audio, between the both groups of the current study and any extension study, would be beneficial to see if clinicians can distinguish the differences and further delineate any speech characteristics displayed by the participants.
Additionally, concussion management protocols should consider including DDK tasks, for these tasks could yield a better measurement of an athlete’s severity. Additionally, DDK tasks can also highlight impairments that can otherwise be masked by the athlete, or not immediately evident in behavioral and neurocognitive testing.

## 5.9 Limitations

One of the limitations of the current study is the sample of convenience used for the control group. This group is primarily composed of UTEP students, most of which are non-athletes. Additionally, a small sample size, for both groups, continues to be a limitation. A larger sample size will aid in obtaining normal distribution across groups and may further increase statistical significance. Finally, due to limited number of athletes in the SRC group, a statistical analysis could not be calculated to account for fatigue: beginning versus the end, condition versus condition, or adolescent versus adult comparisons. Increasing the sample size for both groups will aid in controlling for these effects.

Another limitation is that all of the adolescents in the current study, for the control group, were siblings of participants in the control group as well. Because they are from the same family, this could have biased the data by not providing enough heterogeneity in the control group, since there were no family members included in the SRC group.

Additionally, another limitation includes that the p-values were not adjusted when running multiple comparisons for the statistical analyses. Therefore, this could have increased the risk of a Type-I or Type-II error.

## 5.10 Considerations

It is recommended that the control group be comprised of athletes, not within the same family, to adequately compare their performance to athletes suffering a concussion. In addition,
it is recommended that the groups be matched by age, gender, education, and further down the line even site of lesion. For further facilitation of matching participants to the SRC group, a future investigator can pull participants from the remaining 32 participants of the original 50 collected in this study.

Due to eliminating a few participants in the SRC group, there are not enough individuals in the SRC group beginning with DDK tasks and motor limb tasks to account for fatigue within the SRC group. Therefore, continuing to randomize the motor speech and limb tasks is recommended, focusing on eliciting the DDK and the motor limb tasks in the beginning.

This study extended the age range to include adolescents. As a result, the adolescent population in both groups is extremely limited in size. Future considerations should include extending the pediatric population, within both groups, to include more adolescents.

It is recommended that a power of analysis be run before recruiting for the control and experimental groups. This will accurately guide the next primary investigator to the exact number of participants needed in order to reach accurate statistical significance.

As the groups grow, normal distribution and equality among groups will be achieved. Therefore, more complex statistical analysis can be calculated such as logistical regressions.

Additionally, the inclusion criteria for the SRC group should be revised to not disqualify any SRC participant that has acute hearing loss, which might be a result of their concussion.

5.11 Conclusion

The experimental findings of the current thesis are promising. An SRC/mTBI not only impacts what is already currently known: ocular, vestibular, cognitive (Collins, et al., 2013) and motor limb movements (DeBeaumont et al., 2009), but also impacts the motor speech mechanism during the acute and subacute phase. The experimental findings show that athletes


exhibit a motor slowing of articulators in comparison to control subjects. Cannito (2014) delineates the process Speech Language Pathologists should follow when encountered by cranial damage, following a SRC, which can ultimately lead to a type of dysarthria. Cannito (2014) explains that if there is evidence of cranial nerve involvement, individuals should be given a comprehensive motor speech evaluation that includes: a case history, speech mechanism examination, formal perceptual speech assessment, standardized dysarthria testing, and examination of non-speech motor behaviors.

Despite the improvements in concussion rules and regulations, the outcome and consequences of a SRC continue to weigh heavily on the athletic society. In the current study the majority of the athletes took longer than 10 days to begin the return-to-play protocol. For the most part, athletes are returned to the classroom or practice within the 7-10 day time frame. The current study shows that athletes are experiencing symptoms and impairments past the 7-10 day time frame. Therefore, a conservative approach when initiating the return-to-play protocol is recommended for all athletes. Taking an individualized and conservative approach can ensure the prevention of detrimental effects such as those that result in PCS, CTE, and/or SIS.

Additionally, the results of the current study show that adolescents are in fact more symptomatic for longer periods of time post-SRC in comparison to adults. Parents, coaches, trainers, teachers, administrators, speech-language pathologists, and physicians must all work together to not only to provide individualized care, but also to ultimately become the athlete’s fiercest advocates in caring for their brain- their future.

“We are beginning to recognize that white matter lesions may be responsible for more symptoms than previously thought and that they may be the source of the ongoing neuro-cognitive issues that affect patients following mild traumatic brain injury” (Park et al., 2008). If
Park and colleagues (2008) are correct in determining that white matter deterioration is an ongoing process, then athletes are risking a lot more than they bargained for. One must ask, is it worth it for athletes to risk so much in response to family tradition, coach pressures, and in hopes of attaining a dream?
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CURRICULUM VITA

Jessica Marie Hewitt was born in El Paso, Texas. The only daughter of Max Hernandez and Carmen Diaz. Jessica Marie Hewitt graduated in three years from Del Valle High School, El Paso, Texas. She received her Bachelor of Arts in English Teaching, with a minor in Education, from The University of Texas at El Paso in the Summer of 2008. Soon after, she began teaching at Ysleta High School, as an English teacher, for the next four years. After her first year of teaching, she decided to pursue a Master of Arts in the Teaching of English, at the University of Texas at El Paso, which she completed in May of 2013. She was then accepted to the Program of Speech-Language Pathology, at The University of Texas at El Paso, in the Fall of 2013. She volunteered 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 Bilingual Speech Language Pathology and Concussion Management.