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Examining Articulatory Kinematics Using Diadochokinesis in Concussed and Non-Concussed Individuals

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EXAMINING ARTICULATORY KINEMATICS USING DIADOCHOKINESIS IN CONCUSSED AND NON-CONCUSSED INDIVIDUALS

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For my loving parents,
James and Kathleen Dolan,
and my grandmother,
Leola M. Leonard,
for believing in me when no one else did.

And for my grandfather,
Donald E. Leonard,
for teaching me the importance of
setting high goals,
having Faith,
and staying true to myself.

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ABSTRACT

Cognitive and communicative deficits associated with traumatic brain injury are an active area of research. However, no research to date has reported on the functionality of motor speech following a concussion. A common tool used to evaluate the motor speech status of potentially impaired individuals is the measurement of the diadochokinetic speech rate. The purpose of this study is to investigate diadochokinetic speech rates in individuals who experience a sports-related concussion. Determining the nature and extent of motor speech involvement post concussion will contribute to the diagnosis, prognosis, and management of recovery. The present investigation will determine; (i) if there is a statistically significant difference in duration of diadochokinetic speech rates between concussed and non-concussed individuals and; (ii) if there is s a statistically significant correlation between performance on the diadochokinetic task versus performance on the finger repetition task between concussed and non-concussed individuals. Ten healthy adults with no history of past or current concussion were compared to ten adults diagnosed with a concussion at the time of their evaluation. diadochokinetic tasks were used to assess motor speech function. Results showed that, relative to controls, concussed individuals showed; (i) significant motor slowness in diadochokinetic and finger repetition tasks in the concussed participants; and (ii) no significant correlation between slowed finger repetition tasks and diadochokinetic tasks.

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CHAPTER 1: INTRODUCTION

The incidence in concussion has increased over the years, which has caused an increase in research on the topic (Beaumont et al., 2009). According to the Centers for Disease Control and Prevention, approximately 1.5 million to 3.4 million individuals in the United States sustain a concussion in each year. The number of sports-related concussions may increase unless preventative measures continue to progress. A concussion or mild traumatic brain injury (mTBI) is a type of head injury induced by biomechanical forces. It is a complex pathophysiological process affecting the brain. The pathophysiological processes are: (i) abrupt neural depolarization; (ii) release of excitatory neurotransmitters; (iii) ionic shifts; (iv) changes in glucose metabolism; (v) altered cerebral blood flow; and (vi) impaired axonal function (Salvatore & Fjordbak, 2011). Individuals who suffer head injuries may exhibit a communication deficit in speech and/or language depending on the location of damage to the nervous system (Toshniwal & Joshi, 2010). Trauma to the brain can have effects on the overall speech mechanism resulting in a neuromotor speech disorder also known as dysarthria (Kuruvilla, Murdoch, & Goozee, 2007). Therefore, an investigation of articulatory movements using diadochokinesis could provide an understanding of how motor speech is affected post-concussion.

Diadochokinesis is a traditional component used to assess motor speech capabilities for examination of speech disorders of various severities as well as examination of individuals with various levels of cognitive and linguistic ability (Tjaden & Wang, 2003; Wang, Kent, Duffy, Thomas, & Weismer, 2004). Diadochokinesis refers to the maximum rapid syllable sequence repetition rate in the form of /p^t^k^/(Tjaden & Watling, 2003). The alternating motion rate (AMR) refers to single syllable repetition rate as in /p^/, while

the sequential motion rate (SMR) refers to repetition of syllable sequences such as /p^t^k^/ (Tjaden & Watling, 2003). Although maximum performance tests using syllable repetition have been criticized because it does not necessarily represent natural speech, they do provide information regarding the upper limits of coordinated serial movement function (Cannito, Ege, Ahmed, & Wagner, 1991). The task should be interpreted as a test of motor function rather than an evaluation of speaking ability (Cannito et al., 1991). Considering the dysfunction of motor skills typically seen early on in clinical manifestation of chronic TBI (Beaumont et al., 2009), motor speech should be assessed using diadochokinesis in accordance with motor skills after a traumatic brain injury. A number Resarch shows that there is paresis in the facial muscles after a traumatic brain injury (Toshniwal & Joshi, 2010). Additionally, TBI subjects show a deficit in prosodic, resonatory, articulatory, respiratory, and phonatory aspects of speech production (Toshniwal & Joshi, 2010). Response characteristics determined by diadochokinesis such as velocity and duration are important to understand the function of the speech mechanism after a concussion is sustained; such that the information gained can potentially provide information about prognosis for recovery.

Kent, Netsell, & Bauer (1975) reports restricted range and slower rates of speech muscle movement as well as limited flexibility in the tongue of a patient with post-traumatic brain injury. The same study also identified narrow paths of lingual movement throughout speech production. More recently, a study performed by Goozee, Murdoch, Theodoros. & Stokes (2000) revealed that a dysarthric patient with traumatic brain injury, had difficulties controlling placement of the tongue during speech production. The research study completed by Ziegler, Hartmann, & Hoole (1993) found significantly greater

syllable durations for a traumatic brain injured group compared to a control group when producing CVC segments such as C=/p,t,k/ and V=/i,y,u.a/. Wang et al. (2004) reports that TBI subjects have slower syllable rate, temporal and energy maxima irregularities, normal median voice onset time values with large variation, and a number of speech production abnormalities on alternating motion rates (repetition of the same syllable).

A study by Toshniwal & Joshi (2010) determines that the duration of a stressed word is longer in patients with TBI due to the neuromotor coordination deficiencies and weakness. These individuals have slurred speech resulting from a lack of precision and adequate force in articulatory movements. The weakness of articulatory movements increase the amount of time it takes to produce an individual speech sound or syllable (Toshniwal & Joshi, 2010).

The study by Wang et al., (2004) revealed decreased speech intelligibility among TBI patients. Explosive speech quality, breathy voice quality, phonatory instability, multiple bursts, lack of burst, continuous voicing, and spiranization were all demonstrated in the TBI subjects through a qualitative analysis (Wang et al., 2004). Additionally, voice impairments were noted in some TBI subjects (Wang et al., 2004). Some of the abnormalities found may have been attributed to the deficits in laryngeal control and vocal tract control (Wang et al., 2004). These abnormalities may not have been detected otherwise if a qualitative analysis was not completed (Wang et al., 2004). After reviewing the literature, there is a general agreement that individuals who suffer traumatic brain injury exhibit communication difficulties (Toshniwal & Joshi, 2010). Individuals suffering from a head injury may show difficulties with prosody, resonance, articulation, respiration, and phonation during speech production (Toshniwal & Joshi, 2010). Since concussions

represent a mild form of traumatic brain injury, these patients may also demonstrate the same deficits causing their speech intelligibility to be diminished.

Beaumont et al. (2009) investigates the effects of having sustained a concussion 30 years prior to testing on cognitive and motor functions. The authors assessed motor functions using an alternating motor speech and limb task. An auditory oddball paradigm was used to evoke P3a and P3b brain responses. Compared to controls, former concussed athletes had: (i) poorer performance on neuropsychological tests; (ii) significantly delayed P3a and P3b components and (iii) significantly reduced movement velocity in motor speech and motor limb tasks. Velocity was the only statistically significant contributor to slower motor speech and motor limb movements (Beaumont et al., 2009).

It is presumed that motor system dysfunction will affect both motor speech and motor limb tasks. This is primarily because the pyramidal neurons of the primary motor cortex control both speech and limb movements. The pyramidal neurons receive information from the somatosensory cortex and thalamus (Kandel, Schwartz, & Jessell, 2000). However, these motor neurons receive information from two, different pyramidal tracts that are responsible for voluntary movements. The corticobulbar tract leads to the motor neurons in the nuclei of the brainstem (Kandel, Schwartz, & Jessell, 2000). These nuclei stimulate the muscles of the face, jaw, tongue, and pharynx via the cranial nerves (Kandel, Schwartz, & Jessell, 2000). The corticospinal tract stimulates the motor neurons in the spinal cord responsible for the body's axial muscles, as well as the arms and legs (Kandel, Schwartz, & Jessell, 2000). Furthermore, motor limb and motor speech movements are located in different anatomical locations on the cortex, which may

contribute to differences across repetitive motor movement task scores between the limbs and speech.

There has been limited research of speech parameters in patients suffering from a traumatic brain injury (Toshniwal & Joshi, 2010); even fewer attempts have been made to study it after an mTBI, and there have been no attempts to study it specifically after a concussion is sustained (Kuruvilla, Murdoch, & Goozee, 2007). The objective of the present study is to investigate the clinical importance of diadochokinetic rates for concussion management and sports medicine purposes. Determining the differences between diadochokinetic rates and motor limb movements following a concussion will provide for a more accurate diagnosis and prognosis for recovery. This study purports two main objectives.

The first objective is to determine if there is a statistically significant difference in the duration of diadochokinetic tasks between concussed and non-concussed individuals. It is necessary to determine the speech motor movement restrictions in order to increase the understanding of the motor system's reaction to a concussion. There have been no publications to date that report motor speech deficits following a concussion. Current concussion diagnostic criteria do not evaluate or consider motor speech deficits. It is important that data be collected post-concussion to better evaluate speech recovery. Also, normative data needs to be established for DDK rates so that practitioners have comparative values when assessing motor speech in post-concussive individuals.

The second objective is to determine if there is a statistical correlation between performance on the diadochokinetic task versus performance on the finger repetition task between concussed and non-concussed individuals. The timed results of the

diadochokinesis task and finger repetition task will be recorded and evaluated to determine if there is a relationship in speed, time, and duration of motor limb movements and motor speech movements.

This study compares two groups of different individuals. Therefore, this study is a group design between concussed and non-concussed individuals across diadochokinetic, finger repetition, and stopwatch tasks. The independent variable is dichotomous and includes the concussed and non-concussed groups. The dependent variables are continuous and are represented by the performance on diadochokinetic task, finger repetition task, and stopwatch task.

The data analysis is based on the research questions below:

1. Is there a statistically significant difference in duration of diadochokinetic tasks between concussed and non-concussed individuals?

Hypothesis: The concussed individuals will take more time in carrying out the diadochokinetic task than will the non-concussed individuals.

An acoustic measurement analysis using the Computerized Speech Laboratory by Kay Elemetrics is used to determine the difference between times in diadochokinetic rates. The Computerized Speech Lab is refined to assess the standard features for speech analysis by offering signal-to-noise performance analysis along with waveforms and spectrograms.

2. Is there a statistical correlation between duration of the diadochokinetic task and duration of the finger repetition task between concussed and non-concussed individuals?

Hypothesis: Accuracy of finger repetition movements will not be statistically correlated with slower diadochokinetic rates.

A data analysis is used to determine the correlation between the time elapsed for the participants to complete the diadochokinetic task and the finger repetition task. The diadochokinetic tasks will be compared to the results from the finger repetition task to understand if there is a correlation between speech motor movements and motor limb movements.

CHAPTER 2: METHODS

Participants

The experimental group is comprised of eight English-speaking concussed patients ages 18-25, who are currently diagnosed with a concussion. Since the participants for the concussed group are tested and evaluated at the University of Texas at El Paso Concussion Management Clinic, the diagnoses of the concussion group are recorded and readily available. Participants are included in the study if they meet all of the following: a current diagnosis of a concussion, good physical condition, no history of speech or language disorders, no hearing loss, no history of drug/alcohol abuse, no previous history of psychiatric illness, learning disability, neurological history (seizure, central nervous system neoplasm, or brain tumor) or TBI unrelated to concussion.

The study includes a control group consisting of ten English-speaking individuals with no current diagnosis of concussion between the ages of 18 and 25. Participants are included if they meet all of the following: no current diagnosis of concussion, good physiological condition, no history of speech or language disorders, no hearing loss, no history of drug/alcohol abuse, no previous history of psychiatric illness, learning disability, neurological history (seizure, central nervous system neoplasm, or brain tumor) or TBI unrelated to concussion.

Participants are recruited from the University of Texas at El Paso (UTEP) Concussion Management Clinic, the UTEP Speech, Hearing, and Language Clinic, the UTEP College of Health Sciences, and UTEP Sports Management/Medicine. The recruitment process consists of face-to-face meetings, and the principal investigator maintains contact with each participant via telephone, mail, and electronic mail.

The purpose of the research study, all procedures, and benefits/risks associated with the research study are explained to each participant. Participants provided written informed consent to participate. Participants were given the opportunity to ask any questions he/she may have in regards to the research study or their participation. Participants are given a verbal explanation about their right to participate/withdrawal for the research study at any time.

Institutional Review Board Approval

The study proposal has been reviewed and approved by The Institutional Review Board at the University of Texas at El Paso. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research is conducted in accordance with this approved submission. The IRB reference number for this study is 323337-1.

Setting

The present study takes place in the UTEP Speech, Hearing, and Language Clinic as well as in The UTEP Concussion Management Clinic. Each of these areas is optimal for research due to their quiet and professional environment. The diadochokinetic tasks are recorded in a sound-treated booth to ensure optimal performance and evaluation.

Confidentiality

Data collection, data entry, and data analysis is the responsibility of the principal investigator. All data is kept in a locked cabinet within the UTEP Concussion Management Clinic in the Speech-Language Pathology Department. Access to the cabinet was only given to the principal investigator and faculty advisors. For additional protection, electronic data is stored in a computer only accessed by a password known only to the principal

investigator and the faculty advisors. The participants' responses that are recorded on the Computerized Speech Laboratory (Kay Elemetrics) corresponded with a number code for identification purposes. All recordings remained in a locked cabinet only accessed by the principal investigator and faculty advisors. The audiotapes will be destroyed after they are evaluated.

Acoustic and Perceptual Measures

Recordings are made in a sound-treated booth with high quality equipment (digital recorder, digital voice recorder, condenser microphone, and headphones) in the UTEP Speech, Hearing, and Language Clinic. The samples from the diadochokinetic tasks are analyzed using the Computerized Speech Laboratory (Kay Elemetrics), sampling at 10kHz and a dynamic range of 16 bit (Ackerman & Hertrich, 1994). The acoustic signal is presented to the participants using a condenser microphone positioned 9.0 cm from the center of the oral cavity. The diadochokinetic tasks are analyzed to determine if differences occur in the overall rates between concussed and non-concussed individuals.

Procedures

The experiment consisted of one, two-hour testing session. The session included administration of the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT), the post-injury concussion questionnaire, the Pitt and Post traumatic stress disorder questionnaire, Romberg test, the 3-D shape assessment, the verbal fluency assessment, the Wii Basic Balanace Test, a hearing screening, the diadochokinetic task, the stopwatch task, and the finger repetition task.

Materials

ImPACT-Testing and Computerized Neurocognitive Assessment Tools

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is the most scientifically certified computerized concussion evaluation system across a number of different age ranges. The ImPACT is a twenty-minute test used as a standardized tool in clinical management of concussions. The ImPACT was chosen for this study because it features a number of different post-concussion assessment tools and measures multiple aspects of cognitive functioning including: attention span, working memory, sustained and selective attention time, response variability, nonverbal problem solving, and reaction time. Concussed individuals are administered the ImPACT. The control group was not administered the ImPACT test. This study also uses the test's demographic questionnaire to confirm any speech and/or language disorders, psychological disorders, learning disabilities, and neurological history to ensure participation is validated.

Post-Injury Questionnaire

The concussed group is given a post-injury questionnaire to gain information about their concussion. The questionnaire records information about the injury being assessed. The questionnaire gains information on the description of the injury, whether the individual remembers how the injury occurred and the individuals' description of the injury. The exact site of the injury, any loss of consciousness, and the individual's description of pre- and post-injury events were also recorded on this questionnaire. Lastly, this questionnaire gains information on the types of symptoms the individual is experiencing after the concussion.

Romberg Test

The Romberg Test is given to the concussed group. The Romberg Test is a neurological test for balance. An individual having difficulties with proprioception, typically after a concussion is sustained, can still maintain balance while standing using vision and vestibular function (Khasnis & Gokula, 2003). The participant stands with his/her eyes closed and his/her arms stretched forward. The primary investigator watches the participant to determine if he/she is demonstrating any signs or symptoms that could indicate issues with balance such as swaying, wobbling, or loss of footing. The primary investigator then pushes the participant forward to determine if balance is maintained. If the participant struggles in any way to maintain balance, a positive Romberg is determined. A positive Romberg suggests that the loss of motor coordination is sensory and a negative Romberg suggests that the loss of motor control is cerebellar in nature.

Pitt and Post Traumatic Stress Disorder (PTSD) Questionnaires

The Pitt and PTSD questionnaires are administered to the concussed group. The Pitt questionnaire is given to gain insight on the participants' current ability to answer written questions about themselves, the dates, current location, month, day of the week, etc. This questionnaire is given to determine if the participant is currently having trouble with memory and other cognitive skills. The PTSD questionnaire is given to gain insight about the participants' current stress levels and feelings after the injury occurred. The questions include, but are not limited to determining if the participant is currently: having nightmares, having flashbacks, having trouble keeping thoughts of the incident out of his/her mind, feeling detached, etc. The answers given to these questions inform the primary investigator if there are any negative feelings causing a psychological disorder

known as post-traumatic stress disorder. If the participant is experiencing any of the above, a referral will be made to a physician

3-D Shape Assessment

The 3-D Shape Assessment requires the concussed participants of to draw five 3-D objects to the best of their ability. All of the objects vary in complexity and difficulty. Participants receive a passing score if all of the 3-D details are drawn. If the details in any of the five drawings are not represented, the participants receives a failing score for the task. This assessment is used to gain insight on the individuals' depth perception and attention to detail.

Verbal Fluency Assessment

The verbal fluency test is given to both the concussed and non-concussed groups to gain insight on the speed and accuracy in naming words as well as the participants' ability to recall certain items. Each participant is given one minute, timed by the primary investigator, to produce as many words as possible beginning with the prompted letter. The participant is informed that proper nouns would not be counted in addition to adding suffixes or prefixes onto words. The letters assessed are "s", "f", "a", "j", "r". Participants are then asked to name as many animals as possible within a one-minute timeframe. The primary investigator records the number of words produced on a separate sheet of paper. The responses are then compared to normative data to determine any notable deficiencies.

Nintendo Wii Basic Balance Test

The Wii basic balance test is administered to the concussed participants. The test is administered to gain insight on the participants' balance skills. The Nintendo Wii Balance Board is placed approximately six feet from the television screen. Each participant is read

the directions verbally until the criteria are understood. Each participant has 30 seconds to complete five balancing tasks. Task difficulty increases as the program progresses. The Nintendo Wii software records the number of seconds required for each participant to complete the balancing task. Each participants scores were compared to normative data to determine any notable differences.

Hearing Screening

Each concussed and non-concussed participant receives a sweep-check hearing screening at The University of Texas at El Paso Speech, Hearing, and Language Clinic. Each participant is screened at four frequencies (500Hz, 1000Hz, 2000Hz, and 4000Hz). The screening began at 1000Hz. Responses are identified using a "+" and a "-" to identify no response. Any participant failing to respond to two of the four frequencies in the same ear will be re-screened within three to four weeks. Any participant failing to respond to two of the four frequencies in the same ear on the second sweep-check will receive a referral. Every participant is required to pass the hearing screening on the first trial to participate in this study.

Stopwatch Task

Each concussed and non-concussed participant is given a digital stopwatch. Participants are instructed to start and stop the stopwatch as quickly as possible using their dominant hand. Each participant is given two practice attempts. The participants will engage in three trials of starting and stopping the watch. Each reaction time is recorded separately and averaged to determine the overall reaction time. The reaction time measures the time required for participant to start and stop the stopwatch during the stopwatch task.

Diadochokinetic Task

Each concussed and non-concussed participant is seated in a chair in a sound-treated booth and kept elbows close to the trunk. A condenser microphone is positioned 9.0 cm from the center of the oral cavity; the microphone is secured using a neck yoke. Participants were instructed to repeat the syllables /p^t^k^/ twelve times as rapidly and precisely as possible. Each participant receives two practice productions of the diadochokinetic task to ensure that the criterion was understood thoroughly before the task began. Only ten productions of /p^t^k^/ is timed in order to evaluate results with normative data. The first and last productions are produced to ensure that no errors or confusion are present on the part of the subjects.

Finger Repetition Task

Each concussed and non-concussed participant is seated in a chair across from the principle investigator. Participants are instructed to alternate finger movements by touching the thumb to the index finger, followed by the middle finger, and then by the ring finger in an alternating motion. Each participant was told to be as accurate and as quick as possible. Each participant receives two practice productions of the finger repetition task to ensure that the criterion was understood thoroughly before the task begins. Ten repetitions of the finger task are timed. The first and last productions are produced to ensure that no errors or confusion are present. Each participant was instructed to use his or her dominant hand. The participants are recorded on a video camera while completing the finger repetition task.

Acoustic Analysis

An acoustic analysis is computed for both the concussed and non-concussed group to calculate the temporal variables of the diadochokinetic task. The Computerized Speech

Lab by Kay Elemetrics is used to calculate the diadochokinetic rate in the wideband digital spectrographic display. The waveforms are displayed for the syllable repetitions of interest. Cursors are manually placed at the onset for the second production of /p^/ in the DDK task and the final glottal pulsing of the last /k^/. The Computerized Speech Lab calculates the duration, in seconds, using the cursors as the beginning and end points. The total and average diadochokinetic tasks are calculated for each group. Acoustic measures are performed for syllable production occurring within a thirteen second time window during the diadochokinetic task. The thirteen-second time window was chosen by reviewing the recordings and determining the longest time interval for which the participants continuously produced syllables without breathing or hesitation. The beginning of the analysis window is defined as the onset for the second production of /p^/ in the diadochokinetic task. The second onset of the release for /p^/ was chosen as the starting point in order to diminish controversy and error in the first repetition of (/p^t^k^/). The end of the analysis window is defined as two seconds after the last /k^/ production.

The diadochokinetic rate is defined as the number of seconds required for each individual to produce ten repetitions of /p^t^k^/. The diadochokinetic rate durations are obtained using waveforms on the Computerized Speech Laboratory by Kay Elemetrics. Each participant's diadochokinetic rate is calculated separately in the acoustic analysis.

Finger Repetition Analysis

A visual analysis using video playback is used to calculate duration for the finger repetition task in both the concussed and non-concussed groups. A stopwatch is used to calculate the duration of the finger repetition task beginning at the first contact of the ring

finger and thumb. The timing stops on the tenth contact of the index finger and thumb. The total and average duration of the finger repetition task rates are calculated for each group. Visual measures are performed for the finger repetition task within a fifteen-second time window. The fifteen-second time window was chosen by reviewing the video recordings and determining the longest time interval for which the participants continuously produced the finger repetition task without stopping or hesitation. The timing begins when the participant's ring finger makes contact with the thumb. The end of the analysis window occurs when the pointer finger makes contact with the thumb on the tenth repetition.

Data Analysis

A one-way between-groups ANOVA (α= 0.05) is used to examine group differences in the diadochokinetic task, finger repetition task, and stopwatch task. All of the recordings and estimates are compared between the concussed and non-concussed group. An additional one-way between groups ANOVA (α=0.05) is used to determine whether there is a correlation between diadochokinetic tasks and ImPACT Composite Scores by evaluating the data and examining if there is a relationship between the severity of the concussion and diadochokinetic tasks.

Correlational Analysis

Pearson's Correlational Coefficient is used to determine whether there is a correlation between the duration of the diadochokinetic task and the finger repetition task. The diadochokinetic tasks are compared to the results from the finger repetition task to determine if there is a correlation between motor speech and motor limb movements. An additional Pearson's Correlation Coefficients is run to determine the relationship between

ImPACT composite scores, total recovery time, the stopwatch task, and diadochokinetic tasks in the concussed and non-concussed group.

Reliability

For each group, five of the diadochokinetic tasks are randomly selected and the diadochokinetic rates are recomputed. Pearson product-moment correlation coefficients are used to index reliability. Pearson product-moment correlation coefficients for the acoustic measures of the diadochokinetic rate task range from 0.968 to 0.998 across groups and acoustic measures.

Three of the finger repetition tasks are randomly selected, and the rate duration was recomputed using video playback. Pearson-product moment correlation coefficients and average absolute error measures are used to index reliability. Pearson product-moment correlation coefficients for the finger repetition task range from 0.999 to 1.000 across groups.

For each participant, only ten of the twelve diadochokinetic task repetitions and finger repetition task repetitions are considered for evaluation. This ensured that each participant was evaluated starting at the second onset of /p^/ and the second onset of the finger movements. Additionally, each participant is given two practice rounds to ensure that there was no confusion on the task it self. During the diadochokinetic task, the microphone is situated at exactly the same distance (9.0cm) from each participant to ensure consistency. Lastly, each participant is given the same instructions verbatim before the diadochokinetic task and finger repetition task begin.

No reliability measures are collected for the stopwatch task due to inter-rater judge inaccessibility. Instead, each participant completes three trials of the stopwatch task. The three trials are then averaged.

Figures 2.1 and 2.2 show the participant demographics.

Table 2.1

Non-Concussed	Gender	Age	Medical Hx	DDK	Finger	Stopwatch
NC1	F	23	None	3.54	5.19	0.34
NC2	F	22	None	3.16	5.06	0.12
NC3	F	20	None	4.2	5.84	0.17
NC4	F	21	None	2.86	3.4	0.13
NC5	M	21	None	4.2	6.34	0.15
NC6	M	22	None	3.65	5.53	0.12
NC7	M	22	None	3.81	8.41	0.24
NC8	F	23	None	3.34	6.31	0.16
NC9	M	21	None	2.81	5.69	0.15
NC10	M	22	None	3.33	6.1	0.14

Table 2.2

Concussed	Gender	Age	Medical Hx	DDK	Finger	Stopwatch
CC1	M	22	None	4.15	5.63	0.13
CC2	F	21	None	4.53	13.02	0.67
CC3	F	21	None	3.69	9.02	0.17
CC4	M	19	None	5.63	6.94	0.15
CC5	M	19	None	4.21	7.78	0.13
CC6	M	20	None	5.95	6.13	0.17
CC7	F	19	None	5.8	7.25	0.16
CC8	F	21	None	4.7	8.4	0.27

CHAPTER 3: RESULTS

Acoustic Analysis

The concussed group shows slower mean repetition rates on the diadochokinetic task when compared to the control group. Figure 3.1 shows the results.

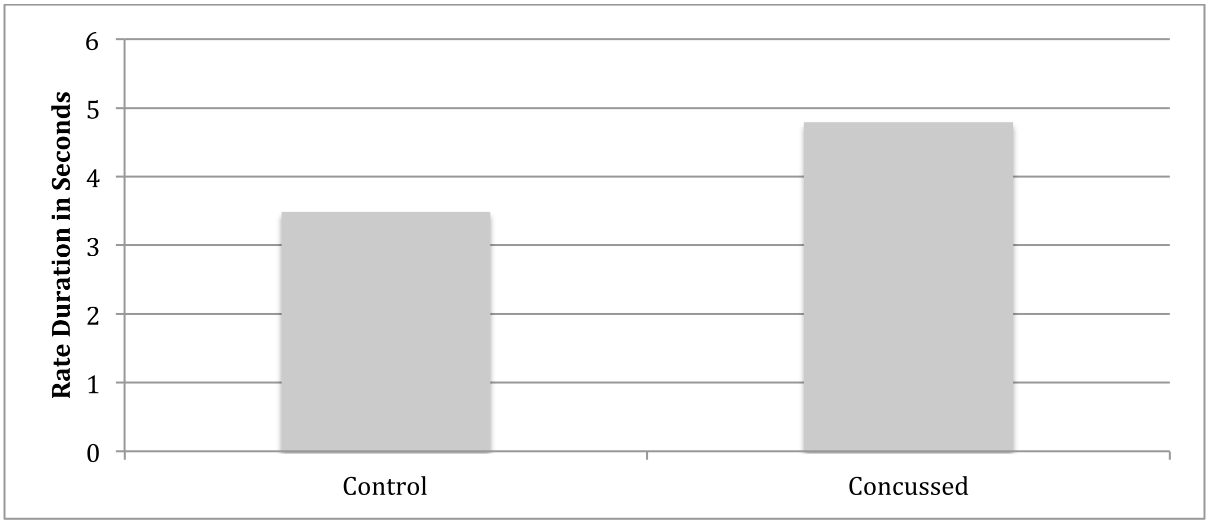

Figure 3.1

Finger Repetition Analysis

The concussed group shows slower mean finger repetition task rates when compared to the control group. Figure 3.2 shows the results.

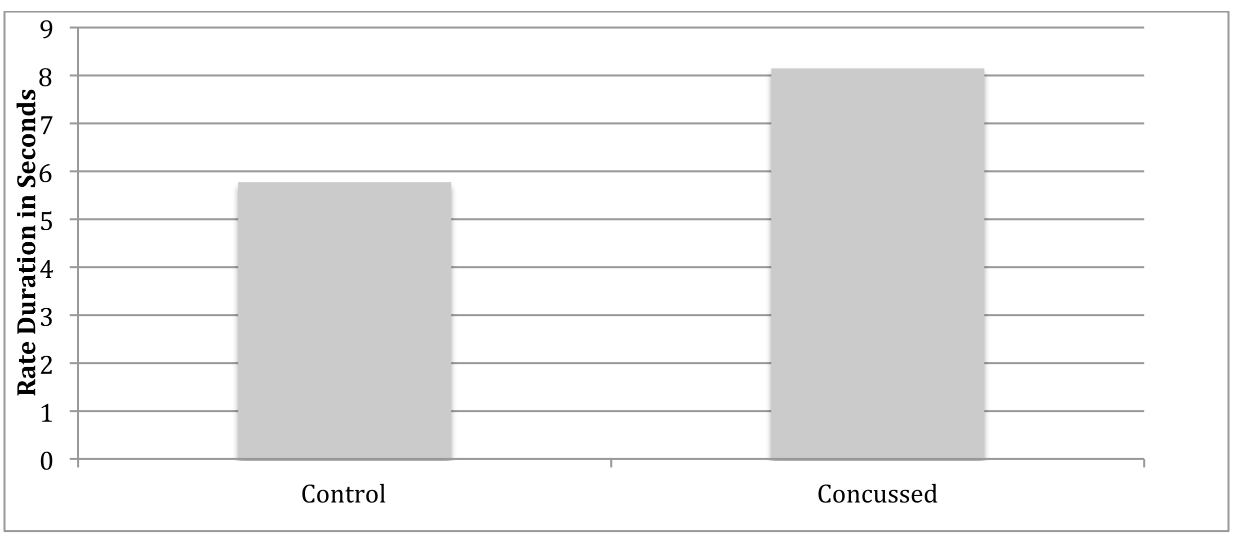

Figure 3.2

Data Analysis

A one-way between-groups ANOVA reveals a statistically significant difference in diadochokinetic tasks between the two groups [F (1, 16)=17.863, p=0.001]. The overall duration mean for the concussed group is 4.79 seconds (SD=0.80), and the overall duration mean of the non-concussed group is 3.49 seconds (SD=0.49).

A one-way between-groups ANOVA reveals a statistically significant difference in finger repetition tasks between the two groups [F(1, 16)=7.896, p=0.013]. The overall duration mean for the concussed group is 8.14 seconds (SD=2.28), and the overall duration mean of the non-concussed group is 5.78 seconds (SD=1.25).

A one-way between-groups ANOVA reveals that there is no statistical significance in the stopwatch task between the two groups [F(1, 7)=1.2, p=0.309]. The overall average for the concussed group is 0.22 seconds (SD=0.18), and the overall average for the non-concussed group is 0.14 seconds (SD=0.02). The stopwatch task indicates slower reaction times for the concussed group on average

Correlational Analysis

Pearson's Correlation Coefficient shows that there is a low negative correlation between the motor tasks in the concussed group, r=0.33 (P=.46, 95% CI -0.87 to 0.56). In some participants, diadochokinetic tasks increase as the finger repetition tasks decrease and vice versa. However, the two motor skill tasks do not represent linear dependence in most cases. Figure 3.3. shows the results.

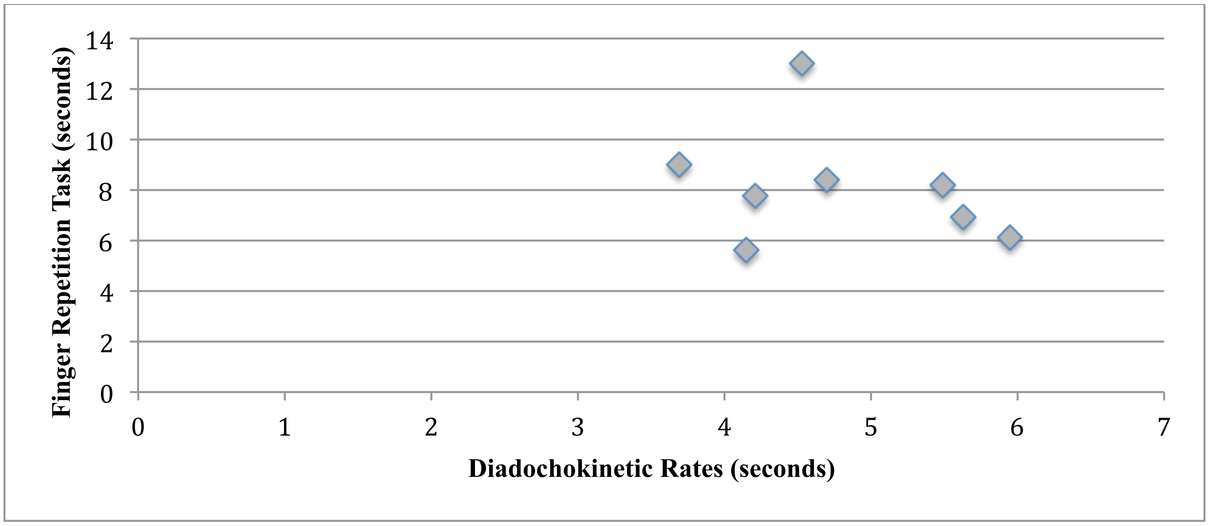

Figure 3.3

The diadochokinetic tasks are compared to five of the ImPACT composite scores. The visual memory (VisM), verbal memory (VbM), cognitive efficiency index (CEI), total symptom scores (TSS), and reaction time (RT) are the composite scores being evaluated. Composite scores are correlated with diadochokinetic tasks to determine if one composite score is indicative of slower motor speech movements represented by the diadochokinetic task. Pearson's Correlation Coefficient is used to determine the correlation between each composite score and diadochokinetic tasks. The composite score with the greatest relationship to slower diadochokinetic tasks is the CEI, r=-0.33 (P=0.46, 95% CI -0.87 to 0.56). The CEI measures the interaction between accuracy (percentage correct) and speed (reaction time) in seconds on the Symbol Match portion of the ImPACT test. The results indicate that poorer CEI scores are related to slower diadochokinetic tasks. All other composite scores show no correlation. Figure 3.1 shows the ImPACT composite scores of the concussed participants.

Table 3.1

Subject	VbM	VsM	VMSC	RT	IC	CEI
CC1	99-96%	96-97%	46.6-77%	0.6-29%	1	0.36
CC2	76-15%	75-54%	45.75-76%	0.78-2%	6	0.41
CC3	88-51%	81-93%	41.47-59%	0.55-57%	1	0.37
CC4	91-73%	95-98%	37.35-41%	0.71-9%	16	-0.06
CC5	100-99%	93-93%	51.28-95%	0.57-43%	1	0.49
CC6	96-89%	82-82%	41.83-62%	0.61-29%	7	0.41
CC&	87-59%	71-35%	47.7-85%	0.58-49%	1	0.41
CC8	87-59%	70-35%	48-85%	0.62-50%	1	0.39

The diadochokinetic tasks are compared to total recovery time. Typically, the average recovery time for concussions is 7-10 days (McClincy, Lovell, Pardini, Collins, & Spore, 2006). In this study, concussion recovery times range from 3 days to 16 days with a mean of 11.1 days. Pearson's Correlation Coefficient is used to determine the relationship between total recovery time and diadichokinetic tasks. The results show that there is no correlation between total recovery time and diadochokinetic tasks, r= 0.07 (P=0.88, 95% CI -0.72 to 0.78).

Location of injury and diadochokinetic rates are compared to determine if there is a correlation between the two. First, side of injury (left and right) is correlated with the diadochokinetic tasks. Pearson's Correlation Coefficient is used to determine the relationship between side of injury and diadochokinetic tasks. The results show that there is no correlation between the two tasks, r=-0.24 (P=0.59, 95% CI -0.62 to 0.84).

Lastly, The diadochokinetic tasks are compared with verbal fluency scores. Pearson's Correlation Coefficient is used to determine the relationship between verbal fluency scores and diadochokinetic tasks. The results show that there is no correlation

between verbal fluency scores and diadochokinetic tasks, r=-0.22 (P=0.64, 95% CI -0.84 to 0.63).

CHAPTER 4: DISCUSSION

This study unveils a number of new discoveries about how concussions impact the motor system specific to motor speech and motor limb movements. Interest in concussion is recently growing among scientific researchers and medical professionals due mostly to the increase of incidence in the United States. This study contributes data that will be used to determine concussion severity, clinical evaluations, and new insights on treatment and prognosis for recovery in concussed patients.

This study reveals that there is a statistically significant difference between diadochokinetic rates and finger repetition rates in concussed and non-concussed individuals. No statistical significance was found between the two groups on the stopwatch task. After evaluating the results obtained, it is concluded that individuals suffering from a concussion produce slower diadochokinetic rates and slower finger repetition rates when compared to controls. This supports the idea that there are motoric deficiencies resulting after a concussion. As we know, severe trauma to the brain impacts the overall speech mechanism resulting in a neuromotor speech disorder also known as dysarthria (Kuruvilla et al., 2007). However, there is no research to date that suggests a dysarthric-like speech pattern after a concussion is sustained. Motor limb deficits are known to occur after a severe traumatic brain injury as well as after concussion, and this study supports previous findings on this topic.

Participants included in this study report no history of speech disorders, language disorders, hearing disorders, or other diseases, so we can conclude that the differences in diadochokinetic rates and finger repetition rates are due to the pathophysiological processes that occur when a concussion is sustained. Scientific research concludes that

severe traumatic brain injuries affect the speech and language centers of the brain. However, no research suggests that there are motor speech deficits post-concussion.

Although motor movements of the speech and limb musculature are thought to be innervated with many similarities, but that is not always the case. The speech and limb motor movements are very different in their organization, signaling, and transfer of information. This suggests that concussions may lead to more widespread damage than originally thought.

Considerations

The concussed and non-concussed group did not participate in all of the same diagnostic procedures. The concussed group participates in a more lengthy evaluation process than the non-concussed group. Specifically, the concussed group completes the ImPACT before completing the diadochokinetic task, finger repetition task, and stopwatch task. The nature of the ImPACT test is known to be cognitively fatiguing. The slower diadochokinetic tasks, finger repetition tasks, and stopwatch tasks in the concussed group may be contributed to the fatiguing nature of the evaluations that were completed before the diadochokinetic task, finger repetition task, and the stopwatch task. Fatigue is known to have overall negative impacts on cognitive processes such as attention, memory, and reaction time, which are necessary for quick fine motor movements involved in the diadochokinetic task, finger repetition task, and stopwatch task. It is recommended that the concussed and non-concussed group participate in the same evaluation process to eliminate bias. The diadochokinetic task, finger repetition task, and stopwatch task should be the first evaluation in future replications of this study, so that fatigue can be ruled-out as a factor in producing slower movements.

Originally, it was hypothesized that the stopwatch task would provide insight into the slower nature of the diadochokinetic task and finger repetition task. The stopwatch task was evaluated to determine the differences in reaction time between the concussed and non-concussed participants. Mild traumatic brain injuries typically result in slower reaction times when compared to non-concussed individuals. However, this study reveals that there is no statistically significant difference between groups on the stopwatch task. Therefore, it seems as though reaction time did not have an impact on the slower diadochokinetic and finger repetition rates. However, the nature of the task may not provide sufficient evidence to conclude that reaction time did not contribute to slower motor productions. The stopwatch task evaluates a single moment of reaction necessary to start and stop the stopwatch while the diadochokinetic and finger repetition tasks require a more repetitive-type of reaction time.

Imaging data was not used to determine site of injury. Site of injury was determined through subjective information provided by participants and/or family members. Therefore, bias could have occurred if the patient and/or family member did not accurately provide information regarding site of injury. Therefore, results regarding no correlation between site of injury and slower diadochokinetic and finger repetition rates should be interpreted with caution.

Organization of Motor Movements

The most significant and perplexing finding in this study is that the motor speech mechanism is affected along with the motor limb mechanism after a concussion is sustained. Motor speech movements and motor limb movements are very unique systems that involve many different structures. Therefore, widespread damage to more than one

area of the brain is necessary for a concussion to result in deficits in both motor speech and motor limb movements. For example, the motor speech mechanism is a highly unique system in its genetic, developmental, functional, and phenotypic properties (Kent, 2003). A number of studies of the speech system indicate that these muscles are distinct from other muscles, especially the limbs (Kent, 2003). Moreover, the system of speech production is comprised of several different kinds of muscles that differ in biomechanical and histological properties (Kent, 2003). This shows that concussions impact many different types of muscles at the same time as well as many different structures to demonstrate affects in both the speech and limb motor system.

Speech sound mapping is represented in the temporal, parietal, and frontal lobes (Schiller & Antje, 2003). These regions are also interconnected with subcortical structures such as the cerebellum, basal ganglia, and brain stem (Schiller & Antje, 2003). Each structure is responsible for a different property, but they work together to produce fluent speech. This purports the idea that concussive injuries occurring at any anatomical level of the brain can produce slower motor speech movements.

The unique organization of the two motor systems leads to speculation about a great deal of widespread damage after a concussion is sustained. This study reveals that different anatomical levels, muscles, and cortical networks may be damaged simultaneously after a mild traumatic brain injury is sustained.

Acoustic and Visual-Spatial Signaling

Another way in which the motor speech and motor limb systems differ is the way each is signaled. Movements during speech production are directed toward an acoustic signal that can be interpreted linguistically (Bunton, 2008). Perkell and colleagues (1997)

suggest that the control of motor speech movements utilizes an internal model based on the relation of the vocal tract shapes to their acoustic consequences. Other motor tasks, such as limb motor tasks, are related to an external visual-spatial target and therefore, are very different from speech production (Bunton, 2008).

There is increasing interest on the severity and duration of auditory problems following a mild traumatic brain injury. Some researchers suggest that because the auditory system has greater metabolic needs than most areas of the brain, they are more susceptible to dysfuntion (Vander Werff, 2012). The entire central auditory pathway is susceptible to damage after the neurometabolic cascade begins causing disruption of neuronal membranes and excessive release of neurotransmitters (Giza & Hovda, 2001). Microscopic lesions caused by these secondary events can occur throughout the central nervous system and into the structures of the central auditory system (Vander Warff, 2012).

The auditory brainstem may be the most susceptible to rotational head injuries (Gennarelli & Graham, 1998), which are common in concussion diagnoses. Additionally, the jolting brain against bony ridges of the sphenoid and temporal bones cause damage to the primary auditory cortex (Gutierrez-Cadavid, 2005). As previously stated, the frontal and temporal lobe structures are likely to be affected after a concussion, and these structures have top-down influences on the brain ability to process auditory information (Vander Warff, 2012). Event-related potential measures and comparable behavioral data suggest that the auditory processing modality is more prone to damage than processing in the visual system after a traumatic brain injury (Duncan, Kosmidis, & Mirsky, 2003).

The speech system is signaled through an auditory stimulus and the motor limb system is stimulated through visuo-spatial feedback. This study suggests that both the auditory and visual system may show concurrent dysfunction after a concussion is sustained. Typically, concussions are diagnosed using visuo-spatial assessments such as evaluating the motor limb movements for recommendations regarding return-to-play protocol. This study shows that there is a need for auditory evaluation post-concussion due to its role in producing motor speech movements.

Diffuse Tensor Imaging

The motor speech and motor limb systems require intact white matter in order to function properly. Mayer et al. (2010) suggest that speech production relies on cognitive processes such as attention, executive functions, and memory, which are dependent on intact white matter. A study shows abnormal gait and limb power with decreased white matter (Steingart, Hachinski, Lau, Fox, Diaz, Cape, Lee, Inzitari, & Merskey, 1987). White matter changes are detected in human autopsy, animal studies and diffuse tensor imaging (DTI) studies after a mild traumatic brain injury is sustained. DTI is one of the only imaging methods that can detect structural damage and measure white matter pathology after a mild traumatic brain injury occurs (Mayer et al., 2010). Individuals with mild traumatic brain injury demonstrate increased fractional anisotropy and reduced radial diffusivity in the left hemisphere white matter tracts during the semi-acute phase (Mayer et al., 2010).

A study by Levin et al. (2010) concludes that verbal memory is less efficient in soldiers with mild traumatic brain injury unrelated to PTSD. These authors use DTI to find that "fractional anisotropy of the left and right posterior internal capsule and left

corticospinal tract is positively correlated with total words consistently recalled whereas apparent diffusion coefficient for the left and right uncinate fasciculi and left posterior internal capsule is negatively correlated with this measure of verbal memory" (Levin et al., 2010). However, no between-group differences in visual recall of the spatial location of dots using a selective reminding procedure are found (Levin et al., 2010).

Kraus, Susmaras, Caughlin, Walker, Sweeney, & Little (2007) suggest that there is white matter reduction in the corticospinal tract, sagittal stratum and superior longitudinal fasciculus with mild traumatic brain injuries. Greater white matter pathology was related to more severe deficits in attention, memory domains, and executive functions, which are important for motor planning of speech movements in the same study.

All of these studies provide information regarding structural and functional damage to the speech, language, and motor limb areas of the brain following mild traumatic brain injury. Furthermore, the study by Levin et al. (2010) provides direct evidence of deficient aspects of language and memory following injury. Changes in white matter in the left hemisphere and corticospinal tract suggest that the cranial nerves responsible for speech production as well as motor limb production are deficient post-conussion. The changes in this white matter may be the underlying cause of slower diadochokinetic rates and finger repetition rates in the present study.

Receptor Alterations

The cortical silent period refers to an interruption of voluntary muscle contraction by transcranial stimulation of the contralateral motor cortex. Beaumont et al. (2009) uses four transcranial magnetic stimulation paradigms to assess motor cortex excitability and

the cortical silent period. The results show that the cortical silent period was prolonged three decades post-concussion.

Research finds that the cortical silent period is sensitive to many neurological conditions such as sports concussions, cerebellar ataxia, stroke, Parkinson's disease, and epilepsy (Beaumont et al., 2009). Among these diagnoses, sports concussion and cerebellar ataxia have both been associated with slowness of movement (Restivo et al., 2002). Findings about the cortical silent period may give insight as to why the motor speech and motor limb systems are deficient post-concussion.

Limitations

Although this study reached its aims, there were some unavoidable limitations. The small sample size obtained may not provide sufficient statistical power. A sample of convenience was used, which may not represent an accurate representation of the population. This study attempted to meet the assumptions required for parametric tests. However, the study did not meet these assumptions after all, which may contribute to a poorer statistical estimation. Future replications of this study should consider a large sample size, use of non-parametric tests such as the Whitney-Mann-Wilcoxon test and linear regressions, and use of a randomized selection of participants.

Conclusion

The findings from this study provide compelling evidence that a concussion sustained in early adulthood can have significant impact on an individual's motor speech productions as well as motor limb movements. From a recovery standpoint, return-to-play recommendations should be followed with utmost integrity especially when recommending return to an educational setting. Speech, language, and auditory processing

are essential aspects of success in scholastics. This study provides evidence that all three of these areas are affected up to 16 days post injury. Typically, athletes and students are returned to their environments with no restrictions after 7-10 days of recovery, which may not be long enough even if no symptoms persist. If symptoms are persistent, it is recommended that concussed individuals do not return to normal routines. If individuals return too soon, they are likely to suffer Second Impact Syndrome.

This study shows that behavioral and neuropsychological data may not reflect all of the underlying deficiencies associated with concussions, like motor speech deficits. Therefore, it is important to use measures like diadochokinetic rates to evaluate persistent symptoms that may not be detected by typical concussion diagnostics. Diadochokinetic rates show insight into the fine motor skills that are important in athletics and educational settings. It is important that these deficits are eliminated before returning to play to ensure safety measures and decrease risk for Second Impact Syndrome. In the future, diadochokinetic rates should be used in conjunction with motor limb diagnostics to determine return-to-play protocols.

Symptom clusters have been used to predict recovery time after a concussion is sustained. Once a larger sample is obtained, diadochokinetic rates, verbal fluency assessment, and the Comprehensive Revised Token Test can be included in a speech-related symptom cluster to predict recovery times in concussed individuals who show motor speech deficits.

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CURRICULUM VITA

Lindsay DeAnn Dolan was born in Pittsburgh, Pennsylvania. The only daughter of James A. Dolan and Kathleen A. Dolan, she graduated from Center Area High School, Monaca, Pennsylvania, in the spring of 2006 and entered East Carolina University in the fall on a full athletic scholarship for track and field. While pursuing a Bachelor of Science in speech and hearing sciences, she dedicated her time as a local nursing home volunteer. After receiving a bachelor's degree, she was accepted into East Carolina University's Brody School of Medicine and completed the first year of the Master of Public Health program with a focus in epidemiology. In the fall of 2011, she entered the Graduate School at The University of Texas at El Paso to pursue her dream in becoming a speech-language pathologist. During her graduate studies, she completed a clinical practicum at ReMed of Pittsburgh, a post-acute traumatic brain injury rehabilitation center, and worked as a graduate student clinician at The University of Texas at El Paso's Concussion Management Clinic under the supervision of Dr. Anthony Salvatore.

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