Speech in Athletes in High Contact and Low and No Contact Sports

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Abstract

Background: This study was focused on speech in athletes who participate in high contact sports and low/no contact sports. The primary aim of this study was to explore whether speech rates and fine movements of speech differed between athletes in high contact sports compared to athletes in low and no contact sports when there have been no diagnosed concussions.

Methods: Speech was assessed through a series of experimental tasks, including reading, sentence production and nonword repetition. While neurological patterns were not directly assessed, it was hypothesized that changes in speech behavior may indicate subtle changes in neurological function in college and professional competitive athletes.

Results: The small sample size and unbalanced size of the groups precluded group comparisons via statistical analyses. However, patterns emerged between the high contact and low contact groups suggesting increased and inconsistent variability of movements in athletes that may have sustained repetitive subconcussive events.

Discussion: It is possible that repetitive subconcussive events cause changes in movement variability, processing speed and motor attention in athletes in high contact sports. This exploratory study reveals that the methodologies used may be sensitive to subtle differences between the groups. A further study is required to verify that the patterns indicate statistically valid differences between high and low/no contact athletes.

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Contents

Table and Figures

Tables

Figures

Introduction

America is a country with a relentless love of sports. Families spend their weekends watching it on the television, at their child's game or watching their alma mater play. These beloved sports encompass a wide range, from low contact sports, such as baseball, to high contact sports like football. This love tends to come at a high price - a price higher than a ticket to see the local football team play. It also comes at the potential price of repetitive trauma to the body and brain for the players (Johnson, Neuberger, Gay, Hallett, & Slobounov, 2014). The exact nature of the effect of impact on the brains of athletes is still not completely understood (Wandling, & Guillamondegui, 2015), but research into this question is ongoing in various relevant fields.

Currently there are over a million boys in high school alone playing football and over 70,000 men in college playing football ("Football", 2017). These athletes undergo hundreds of blows to the head in a season on top of many of them experiencing concussions as a result of participation in the high-contact sport of their choice (Broglio, Eckner, Martini, Sosnoff, Kutcher, & Randolph, 2011; Wandling, & Guillamondegui, 2015). A lineman in high school sustains an average of 872 hits to the head in one season, a quarterback, 519 and a receiver, 318. (Broglio et al., 2011). Athletes who endure repetitive contact in their sports, while prone to concussions, are also subject to lesser well-known consequences of collision, called subconcussive events. Subconcussive events are subtle alterations in the brain as a result of traumatic blows to the head that do not result in a diagnosed concussion (Tsushima, Geling, Arnold & Oshiro, 2016). Indeed, an athlete may not know that subconcussive changes have occurred following a blow because of the absence of immediate, obvious behavioral signs (Tsushima et al., 2016).

This study is an exploratory study that focuses on speech in athletes who compete in high and low and no contact sports with the goal of identifying whether or not it is possible to use acoustic and kinematic methodologies to identify whether speech patterns differ between athletes in high contact sports compared to athletes in low and no contact sports. While neurological patterns were not directly assessed, it is plausible that changes in speech behavior may signal subtle changes in neurological function in competitive athletes (Johnson, Neuberger, Gay, Hallett, & Slobounov, 2014).

Review of the Literature

Contact sports are sports that involve direct contact between participants, leaving an individual susceptible to collisions at close or far range with other participants or sports equipment. Contact sports range from ice hockey and lacrosse to basketball and soccer. For this research, contact sports were divided into two categories: high contact and low/no contact sports. Based on the literature, high contact sports include ice hockey, rugby, football and lacrosse (Tsushima et al., 2016). Low and no contact sports include swimming, track and field, tennis, crew, basketball, wrestling, soccer, baseball, skiing and dancing (Kelly, 2010; Tsushima et al., 2016). In the literature, high and low contact sports are classified based on rates of concussions (Tsushima et al., 2016). A high contact sport has relatively high rates of concussions and low/no contact sports have relatively low rates of concussions (Tsushima et al., 2016).

The consequences of these varying rates of concussions are beginning to be established in current research. Among these, known consequences are Chronic Traumatic Encephalopathy (CTE), Traumatic Brain Injury (TBI), concussions and subconcussive events. Each is discussed briefly below.

Chronic Traumatic Encephalopathy (CTE) is known to be “a secondary consequence of repetitive head trauma” (p. 160) such as repetitive subconcussive brain trauma (Belanger, Vanderploeg, & McAllister, 2016). It is common among football players who have never been diagnosed with a concussion (Bough et al., 2012). This might be equated with the physical nature of the sport; many positions in football involve a cycle of intense short bursts of contact followed by a period of rest. These short bursts of high intensity contact over the span of many years are a likely cause of CTE (Bough et al., 2012). CTE is a long-term effect that eventually manifests itself as a “degenerative condition that causes pronounced behavioral changes and cognitive dysfunction” (Belanger et. al., 2016, p. 160). Such changes include alterations in motor coordination that could affect speech. The specific speech changes associated with CTE are slow, slurred, and dysarthric-like speech (Bough et. al., 2012). These manifestations of CTE are not evident until years after athletes have retired from participating in their sport. Not all consequences of contact sports are so elusive as CTE, and traumatic brain injury is one of them.

Traumatic Brain Injury (TBI), often seen in the form of Mild Traumatic Brain Injury (mTBI), is understood to be a disruption in brain function resulting from any amount of force or blow to the head that causes altered consciousness or loss of consciousness (Belanger et. al., 2016). The severity of it is “determined at the time of the injury and not (as is often erroneously done) by level of functioning at some later time point” (Belanger et. al., 2016, p. 159). Since contact sports like football are often characterized by short bursts of intense contact, it may be hard to identify whether a player has sustained a TBI. It is possible that there are multiple times throughout a game when the consciousness of players are altered, but any subtle signs are written off as a part of the game, creating an environment where altered consciousness is acceptable, if not the norm. Since TBI is classified as any altered consciousness, unlike a concussion, a player might not be aware that they are experiencing it or might not know what it is they are experiencing. Even if a player is taken out of a game for an evaluation, Belanger et al. (2016) reports that it can be greatly challenging to identify whether a player presents with mTBI at that moment. Some literature even considers mild TBI a milder version of a concussion (Belanger et al., 2016).

Concussions, caused by a high impact blow to the head "may be somatic, cognitive, or emotional in nature and may include loss of consciousness, amnesia, slow reaction times, confusion, disinhibition, or headaches" (Wandling & Guillamondegui, 2015, p. 1389). These symptoms can last for hours or weeks and vary in severity. Due to how the presentation of concussions vary from case to case, it is difficult to have distinct diagnostic criteria (Wandling & Guillamondegui, 2015). Some methods are used to assess concussions on site, for example, in locker rooms like the ImPACT test, but due to the lack of distinct diagnostic criteria, assessments often prove difficult (Wandling & Guillamondegui, 2015). Concussion symptoms tend to be subjective in nature making it challenging to arrive at a definitive diagnosis (Wandling & Guillamondegui, 2015). Because of this, there is a possibility that a player who has received a concussion might be cleared to continue in the game or practice. The lack of diagnostic criteria and the "play through the pain" mentality that is often adopted by sports can make it difficult to assess and get athletes the proper treatment they need (Wandling & Guillamondegui, 2015).

The absence of a diagnosis in a player who has sustained a blow does not necessarily mean the player has escaped consequences of such impact. Indeed, the literature points out that "subconcussive" changes often occur in a player who has been subject to contact trauma (Tsushima et al., 2016). The field of research in subconcussive events is still relatively young and the criteria, symptoms and definition of what is considered a subconscussive event is still being established. For the sake of this project, subconcussive impact is defined as "an apparent brain insult with insufficient force to cause hallmark symptoms of concussion" (Tsushima et al., 2016, p. 151). Because of the lack of diagnostic criteria, just like with concussions, it is hard to pinpoint the exact moment when a subconcussive event has occurred. It is simply assumed that by playing a contact sport, an individual is naturally exposed to these repetitive events (Abbas et al., 2015). The manifestations of subconcussive trauma include multiple neurologically driven changes in an athlete's behavior (Tsushima et al., 2016), including changes in motor function and speech, language and cognition (Bough et. al., 2012).

Changes in motor function have been seen in a study by Virgilio et al. (2016) examining the effects of heading the ball in soccer players. They discovered that players who participate in frequent heading of the ball show slight changes in corticomotor function resulting in corticomotor inhibition directly after the subconcussive event (Virgilio et al., 2016). They used the Cambridge Neuropsychological Test Automated Battery (CANTAB; Cambridge Cognition, 2017) a computer based assessment tool and EMG (Eletromyography) recording, to assess motor function. Other literature contradicts these findings. A study looking at the exposure ot heading in soccer players found no difference in ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing) scores across groups for players with low, moderate and high exposure (Kontos, Dolese, Elbin, Covassin & Warren, 2011). However, other authors have used the ImPACT test to assess changes to motor parameters (mainly as changes to reaction time) and cognition in athletes in a more acute approach.

Athletes who undergo repetitive subconcussive brain trauma have been recorded as having significant differences in processing speed, reaction time, and other constructs of cognition when compared to their counterparts in low contact sports on the ImPACT test (Tsushima et al., 2016). The ImPACT test is a computerized concussion test that takes around 20 to 30 minutes to administer. It is used at the beginning of a sports team's season to gather baseline performance data and throughout the season when a concussion is expected (ImPACT Test, 2017). It measures attention span, working memory, sustained and selective attention time, non-verbal problem solving and reaction time (ImPACT Test, 2017). Though it is marketed as a concussion assessment tool, it is currenty utilized to assess athletes who may be experiencing subconcussive events as well.

A study conducted by Tsushima et al. (2016) used this test to assess the verbal memory, visual memory, reaction time and processing speed of athletes who participated in high contact sports and low contact sports at the high school level. There were 282 non-concussed male athletes between grades 8 and 12. The results were compared to a small data set of baseline information that had been collected at the beginning of the season. The study found no differences between the two groups for the overall score of the ImPACT test. However, there were a statistically significant differences between the two groups for reaction time and processing speed (Tsushima et al., 2016). A study by Johnson et al. (2014) that examined fMRIs of 24 coed rugby players found evidence to support altered parameters in motor attention. Specifically, they found that athletes post-game had reduced motor attention in addition to demonstrating reduced verbal mediation (the use of speech to learn and problem solve), and memory retrieval (Johnson et al., 2014; Kreutzer, DeLuca, & Caplan, 2011). These studies support the idea that motor and cognitive-linguistic abilities may be altered in athletes who participate in high contact sports.

Whether or not subconcussive trauma is associated with changes in cognition and language is still debated. In a study by Belanger et al (2016), the ImPACT and the California Verbal Learning Test-II (Delis, Kaplan, Kramer & Ocer, 2000) tests were administered to 214 collegiate athletes involved in high contact sports and 45 athletes in non-contact sports. Just as the Tsushima et al. (2016) study observed, there was no statistically significant difference between the two groups in the overall score of the ImPACT test (Belanger et. al., 2016). However, results of the California Verbal Learning Test – II revealed that a subset of the collegiate athletes involved in high contact sports performed below average compared to their peers who were not in high contact sports, as indicated by statistically significant differences in their verbal learning and memory scores (Belanger et. al., 2016). This is where the study by Tsushima and Belanger diverge. Tsushima did not find any difference in verbal or visual memory in athletes engaged in high vs. low and no contact sports (Tsushima et al., 2016). These discrepancies highlight the nature of a growing field; therefore, it is not possible to say with certainty at this time, that subconcussive brain trauma causes changes in cognitive-linguistic ability. It is also not possible to say with certainty that subconcussive brain trauma causes changes in speech behavior.

Speech changes, such as dysarthric and slow speech, have been documented in high contact athletes who have been diagnosed with CTE (Bough et al., 2012). Muscular weakness and atrophy were also noted as peripheral issues that could alter speech production (Bough et al., 2012). However, speech behavior in athletes who are subject to contact without a formal diagnosis of concussion or other neurological damage has not been exclusively examined. This study aims to examine if there are subtle early signs of those long-term speech changes that occur in athletes in high contact sports in acoustic and motor patterns of speech behavior.

Present Study

The present study was designed to examine if it would be possible to use speech research methodology to determine if healthy athletes in high vs. low and no contact sports demonstrated differences in speech motor performance in the absence of a medical diagnosis of concussion, or related- trauma. If patterns emerge that indeed suggest subtle differences in participants in high contact sports (in the absence of a diagnosis of concussion) when compared to participants in low/ no contact sports, then speech may be a sensitive biomarker to potential changes in brain function as a result of susceptibility to subconcussive blows. This study utilizes acoustic and kinematic measures of speech to compare differences in speech between high and low/no contact athletes who have not had documented concussions or other neurological events. The current study is an exploratory project aimed at identifying patterns in the speech of athletes based on the sports they engage in. The findings from this exploratory study will inform future studies in athletes who participate in contact sports.

In summary, the current study has two aims:

Aim 1: To compare speech measures in high contact vs. low/no contact athletes to determine if differences exist between the two groups.

Null Hypothesis: Kinematic, acoustic and/or behavioral differences will not be present between athletes in high contact sports versus no/ low contact sports.

Alternate Hypothesis: There will be a pattern that is indicative of differences between athletes in high contact sports versus no/ low contact sports, such that athletes engaging in high contact sports are expected to demonstrate performance indicative of decreased control and increased variability. This is based on findings from Tsushima et al. (2016) and Johnson et al. (2014) suggesting differences in reaction time and motor planning between athletes who played high contact sports compared to those who played low contact sports.

Aim 2: To explore if specific stimuli and/or methodologies were more sensitive to differences in speech between participants in the two groups.

Null hypothesis: Speech research methodologies (acoustics and kinematics) and/or stimuli will not be sensitive to subtle differences in speech in athletes participating in high vs. low/no contact sports.

Alternate Hypothesis: It was hypothesized that acoustic and kinematic measures would be sensitive to subtle changes in reaction time and motor parameters in speech in athletes participating in high vs. low/no contact sports. This is based on findings from Tsushima et al. (2016) that established that reaction time and processing differences exist in athletes who play high contact sports. Further, kinematic measures of speech have been shown to be sensitive to subtle differences in motor behavior between several other experimental groups (e.g. individuals who stutter) compared to their controls (Smith, Sadagopan, Walsh & Weber-Fox, 2010). Similarly, reaction time measures have previously revealed differences between speech motor planning and programming between control participants and participants with neurological disease (Spencer, 2005).

Further, findings from several previous studies indicate that including varying lengths and complexities of stimuli allow for the assessment of linguistic load on speech performance. For example a study on young adults and 9 to 10 year olds found that increasing the complexity and length in sentences created a higher cognitive load that taxed the speech system (Kleinow et al., 2006). The research done by Sadagopan and Smith (2008) reinforces these findings in a study that examined complexity of sentences based on age; the same pattern was reported, wherein increased complexity of stimuli resulted in a higher cognitive load and more variability in speech movement. These patterns are expected to be particularly prominent for nonword stimuli because they load the cognitive-linguistic-motor systems in unique ways due to their unfamiliarity (Sasisekaran, Smith, Sadagopan, & Weber-Fox, 2010; Walsh et al., 2002).

Investigating consequences of subconcussive events that are associated with no obvious external signs is important within the worlds of high school, collegiate and professional sports. There is potential for speech to serve as a quick, non-invasive and novel marker to identify subtle changes following impact. Understanding early behavioral differences between individuals engaged in playing high vs. low contact sports is a foundational step in prevention and early intervention. This study, unlike others thus far in literature on subconcussive events, specifically assesses speech execution making it a novel study in the field. It contributes to existing literature that addresses changes in athletes' cognition and motor functioning.

Methods

Participants

All participants were recruited from the University of Colorado at Boulder and surrounding areas. The participants in this research were seven males (Mean age = 20.57 years, SD = 0.98 years). Participants fell into one of the two groups based on athletic participation: a high contact group (n= 2; Mean age = 20, SD = .9 years) and the low contact group (n=5; Mean age = 20.8 years and SD = 1.09 years). The high contact group included athletes who participated in high contact sports. High contact sports, based on previous literature, included sports such as ice hockey, rugby and football (Tsushima et al., 2016). It was hypothesized that individuals who are more subject to routine blows to the body and head are more likely to present with subtle cognitive and behavioral changes that result from them (Tsushima et al., 2016). In the present study, participants in the high contact group were compared to participants in a low/no contact group. Low and no contact sports included sports like basketball, downhill skiing and soccer (Tsushima et al., 2016). Participant details are included in Table 1.

All of the participants satisfied the following inclusionary criteria: a) They participated in the high, low or no contact sport for the last three years to ensure that any behavioral effects noted in the study did not reflect isolated events; b) They were currently participating in the sport to ensure consistency in current status of play across participants; c) They were between 18 and 28 years old; d) They had normal hearing; e) They spoke English as their first language – this criterion was enforced in order to avoid any differences in production that might be present with second language learners; f) They reported normal speech, language, learning and cognitive ability and history. Participants with a formal diagnosis of a concussion or other documented brain trauma, and/or any known speech, language, learning, or cognitive diagnoses (e.g. ADHD, Learning Disability) were excluded from the present exploratory study. Additionally, consumption of certain medications like antidepressants and muscle relaxants were cause for exclusion from the present study, because consumption of these medications may be associated with changes in cognitive function (Burda, Czubak, Kus, Nowakowska, Ratajczak, & Zin, 2011). That participants met these inclusionary criteria was determined via a pre-screening questionnaire that participants completed in order to assess eligibility for the study.

In addition to the inclusionary and exclusionary criteria, participants completed four screening tests and one health questionnaire to confirm eligibility on the day of the experiment. These are described briefly below:

a) *Hearing Screening*: In this test, participants heard tones presented through headphones in each ear. In order to pass the screening test, young adult participants responded to a 25 dB HL tone in both ears at 500, 1000, 2000, 4000 Hz and 6000 Hz. All participants passed the hearing screening test.

b) *Vision Screening:* Participants read the last or second to last line of a Snellen eye chart with 100% accuracy (with or without glasses or contacts) from approximately 10 feet away.

c) An *Oral Mechanism Checklist:* Participants demonstrated that structures and functions of the speech articulators fell ‘within normal limits’ during the assessment.

d) The *Saint Louis University Mental State Examination (SLUMS)* (Tariq, Tumosa, Chibnall, Perry III & Morley, 2006): This test assessed attention, working memory, cognition, executive function, language, mental health, reasoning and problem solving. In order to pass the tests, participants were required to obtain a score of 27. All participants scored within normal limits. The mean score among all participants was 28.71 (SD: 1.11). The means for the high and low contact groups respectively are included in Table 2. An independent sample t-test completed on the means and SDs of the two groups revealed that the scores were not significantly different between groups ($t(5) = .29$, $p = .78$).

e) *A health questionnaire:* The purpose of the questionnaire was to obtain information about the participants’ health status at the time of the experiment, including the amount of exercise they got through competitive sports or other activities, relevant medical history and current medications. All participants reported that they were physically active to varying degrees. They all reported having a minimum education level (i.e high school graduation) and all had some experience with education at the college level but none of them had received a subsequent degree (bachelors or Masters ex.).

Stimuli and Data Collection

Only participants who satisfied the inclusionary and exclusionary criteria as well as passed the qualifying tests on the day of the experiment proceeded to complete the next steps of the experimental protocol. Three additional tests were utilized on the day of the experiment.

Table 1
Athletes Sports and Level of Involvement

Participant Code	Group	Age	Sport	Years of involvement	Position	Hours per week participating	Level of Competitiveness
H1	High Contact	20	Rugby	3	Lock	8	Club
H2	High Contact	20	Rugby	4	Flank	8	Club
L1	Low Contact	21	Soccer	15	Keeper	4	Recreational
L2	Low Contact	21	Soccer	18	Midfield	8	Recreational
L3	Low Contact	21	Snowboarding	11	Down Hill	6	Recreational
L4	Low Contact	19	Track/Cross country	15	Distance	14	Division 1
L5	Low Contact	22	Soccer	15	Defense	6	Recreational

Table 2
SLUMS Mean and Standard Deviation for Participants in High Contact and Low/No Contact Groups

All (n = 7)	High Contact (n = 2)	Low/No Contact (n = 5)
28.71 (1.11)	28.5 (2.12)	28.8 (.84)

Standard deviations are included in parenthesis next to mean

They documented baseline speech, language, and cognitive performance prior to the initiation of the experiment. These tests included:

a) The Nonword Repetition Test (Dollaghan & Campbell, 1998). This test is designed to assess phonological working memory capacity, which has been shown to be correlated with nonword repetition performance (Shriberg, Lohmeier, Campbell, Dollaghan, Green, & Moore, 2009). Participants were instructed to repeat nonwords after a pre-recorded aurally presented model, to the best of their abilities. The nonwords increased in length and complexity. Table 3 summarizes accuracy scores (percentage phonemes correct), by participant, for the repetition of all nonwords. The mean and standard deviation for the overall score for the athletes in the high contact group is 92(1.41) and the mean and standard deviation for the overall score for the athletes in the low contact group is 92.8(2.68). These means do not significantly differ from each other, t(5) = 2.57, *p*=.72.
b) The Digit Span subtest of the WAIS-III (Wechsler, 1997) was administered in order to obtain an estimate of working memory function. Participants were asked to repeat a series

of numbers that increased in length forwards for the first part of the test and backwards for the second. The raw and scaled scores of the test are listed in Table 4 below.

Table 3
Nonword Repetition Test Scores

Participant	Overall Score	One Syllable	Two Syllable	Three Syllable	Four Syllable
H1	93%	100%	100%	93%	78%
H2	91%	83%	100%	93%	86%
Mean High Contact Group Scores	92% (1.41)	91% (12.02)	100% (0)	93% (0)	82% (5.66)
L1	94%	92%	100%	96%	96%
L2	91%	92%	100%	96%	83%
L3	91%	100%	100%	93%	83%
L4	91%	92%	100%	96%	83%
L5	97%	100%	100%	100%	96%
Mean Low Contact Group Scores	92.8% (2.69)	95% (4.38)	100% (0)	96% (2.49)	88% (7.12)

Table 4
WAIS-III Raw and Scaled Scores

Participant	Raw Score	Scaled Score
H1	18	10
H2	21	12
Mean High Contact	19.5(2.12)	11(1.41)
L1	17	10
L2	15	8
L3	14	8
L4	17	10
L5	14	8
Mean Low Contact	15.4(1.52)	8.8(1.09)

Raw scores were significantly different for the two groups, t(5) = 2.96, $p = .03$; however, the scaled scores did not significantly differ from one another, t(5) = 2.264, $p = .07$.

c) Reading Fluency Test: This test was completed in order to assess reading level and reading fluency for each participant and to offer an additional context in which speech rate and percent accuracy was measured. Participants were sat in front of a microphone and instructed to read the passage in their usual voice. Table 5 depicts the results from each participant for this test ("Ohio Literacy", 2004).

Table 5
Reading Fluency Test Speech Rate and Accuracy

Participant	Rate (words per minute)	Accuracy in Percent
H1	169.24	100%
H2	189.78	99%
Mean High Contact	179.51 (14.52)	99.5% (.71)
L1	182.9	99%
L2	165.03	99%
L3	161.14	99%
L4	186.34	98%
L5	164.48	98%
Mean Low Contact	171.98 (11.69)	98.6% (.55)

Neither measure significantly differed between groups (p = .49 and p = .12 respectively for reading rate and reading accuracy).

Once all tests were completed, the experiment was initiated. Participants were seated facing a Northern Digital Optotrak (Northern Digital Inc., Waterloo, Ontario) camera system, about 8 feet away from it. A microphone was placed roughly 7 inches from participants' mouths. Infrared light emitting diode (IRED) markers were placed on plexiglas goggles worn by the participant. The goggle had two custom designed plastic splints extending downwards on either side. Eight IREDs were placed on each participant: one was placed on the middle of the forehead, two on the goggles at the level of the corners of the eyes, two on the plastic splints at the level of the corners of the mouth, one each on participants' upper lip, lower lip on the midline of those articulators and one on a splint attached to the bottom of the jaw. The first five IREDs (placed on the forehead and goggles) served as the "rigid body" reference for the tracking of speech movements via the lip and jaw markers (Sadagopan & Smith, 2008). Simultaneously, an auditory signal of participants' performance was recorded using the microphone and a digital recorder, Marantz PMD 670, which digitized audio samples at 48,000 Hz and 16 bits. The audio signal recorded by the microphone and the movement data collected via the Optotrak were synchronized by a data collection unit (ODAU), allowing for the accurate extraction and analysis of speech after the data was collected.

Once the IREDs were placed, participants first repeated the sentence "Buy Bobby a puppy" 15 times following an auditory prompt (beep). The purpose of this task was two-fold: a) it provided an opportunity for each participant to speak with the IREDs in place, thus acclimatizing to the change imposed by marker placement; b) it offered the experimenter an opportunity to record average movement and reaction time measures for a simple sentence task. Next, each participant completed three experimental tasks in random order.

1. Reading task: Participants were instructed to read the Rainbow passage in their "usual voice". This task allowed for accuracy and speech rate to be assessed in a second context.
2. Sentence Production Task: The stimuli used for this study are included in Table 6 below. Participants were instructed to produce the sentences as fast as they could without compromising accuracy. The stimuli were presented via power point slides that were displayed on a screen that was about 10 feet away. Fifteen "blocks" of stimuli were presented with each sentence pseudo-randomized within a block. The sentences varied in

length and complexity and were based on a previous study that examined motor factors in speech as complexity of stimuli increased (Kleinow & Smith, 2006). The stimuli included both simple, declarative sentences and more complex, subject relative clauses. The first and second sentences were simple sentences that were short and long. The third and fourth sentences were complex that were short and long. This variation is important because relative clauses have been shown to be associated with an increase in mean response time, more errors and contributions from both the upper and lower lip during movement (Kleinow & Smith, 2006). Sentences of increased complexity and length were good for the study due to the increased cognitive load that is associated with them (Kleinow & Smith, 2006). An increasingly difficult cognitive load might illuminate differences between how the two groups process and respond to the stimuli.

Table 6
Sentence Stimuli

Sentence 1	The birds and the butterflies played by the pond
Sentence 2	The baby birds and the many butterflies played by the pond
Sentence 3	The birds that saw butterflies played by the pond
Sentence 4	The baby birds that saw many butterflies played by the pond

3. Nonword Production Task: For the nonword task, stimuli were presented aurally via speakers secured to the wall behind the participants. All stimuli were pre-recorded by a native female speaker. Participants were instructed to repeat the nonword as fast and accurately as possible after the auditory model in the carrier phrase, “Say ___________ again” (the nonword replaced the blank). Nonwords were presented in pseudo-random order, such that each nonword was repeated 15 times in all. All of the nonwords started with the syllable /mæb/ and ended with the phoneme /b/ so that there were consistent start and end points that would allow for reliable extraction of data based on lower lip opening

(Sasisekaran, Smith, Sadagopan, & Weber-Fox, 2010). The nonwords increased in length and complexity based on: a) developmental norms and age of phoneme acquisition, b)the number of syllables, which increased from two in the first nonword ("mab") to four in the fourth and fifth, most complex nonwords. The number and complexity of consonants clusters, vowels and diphthongs also increased through the nonwords. Including several nonwords at varying levels of complexity allowed us to assess if changes in production occurred when complexity of stimuli increased.

Table 7
Nonword Stimuli in Latin Script and International Phonetic Alphabet

Nonword 1	Mabshaib /mæbʃeɪb/
Nonword 2	Mabfaisheb /mæbfɑɪʃeɪb/
Nonword 3	Mabshaytiedoyb /mæbʃeɪtɑɪdɔɪb/
Nonword 4	Mabspokweeflaib /mæbspoʊkwifleɪb/
Nonword 5	Mabskrisploistrube /mæbskrisploystrub/

Sentences and nonwords were both included in the experimental protocol for multiple reasons. By having two different tasks, we were able to present the stimuli in two different modalities; aural and visual. While it was not expected that either modality in and of itself would be particularly different for participants in one group vs. the other, it is plausible that working memory abilities depend on modality of input, and therefore interact with speech motor ability in complex ways. Second, the stimuli included allowed the experimenter to examine if differences in familiarity of production affected speech performance, with the sentences including familiar words, albeit in novel combinations, and the nonwords being unfamiliar productions. Athletes in high contact sports might be expected to perform more poorly with unfamiliar productions during the cognitive linguistic load presented by the stimuli.

Measures and Analysis

Three types of data were analyzed in the present study:

1. Reaction time: Reaction time (RT) was manually measured for each production for the "Buy Bobby a puppy" sentence task and for the sentence production tasks. The acoustic analysis software of PRAAT (Boersma & Weenink, 2014) was used for the measurement of reaction time. For both the "buy Bobby a puppy" task and the sentence tasks, reaction time measurements were taken by measuring the time in milliseconds from the onset of the stimulus to the onset of the response. For "buy Bobby a puppy", reaction time was measured from the onset of the beep to the start of the /b/ in "buy". For the sentences, reaction time was measured from the onset of the beep to the start of / ð/ in "the".
2. Behavioral data: Acoustic data was analyzed by having the audio files imported into PRAAT. Each production from the sentence and nonword experimental tasks were transcribed and analyzed for the number and/or percentage of words (sentence task) and phonemes (nonword task) correct. In addition, speech rate and accuracy were recorded for the reading task.
3. Kinematic data: Kinematic data was analyzed by importing the movement signals collected during the "buy Bobby a puppy" task, the sentence and nonwords tasks into MATLAB (Mathworks, 2005) for analysis. The analysis screen displayed two panels: the top panel showed displacement of the lower lip IRED, and the bottom panel displayed the velocity trace corresponding to the movement. Measures of kinematic duration, and movement variability were obtained by segmenting each individual production from the repetitions produced by the participant during the completion of each experimental task for all tasks: "buy Bobby a puppy", sentences and nonwords. Each production was

extracted starting at the peak velocity for the first opening movement for the word or sentence and ending at the peak velocity of the last opening motion at the offset of the production. For example, for the sentence “buy Bobby a puppy”, segmentation began at the peak velocity for the opening movement in “buy” and ended at the peak velocity for the opening movement of “py” in “puppy.” When segmenting the nonwords, the carrier phrase was left out so that only the production of the nonword was extracted. Each extracted sentence or nonword was time and amplitude normalized using procedures described in previous studies (Smith & Zelaznik, 2004). Subsequent to the automated normalization completed by the MATLAB program, two measures of movement variability were obtained: a) Lower Lip/Jaw variability and b) Lip aperture variability (LAVAR; Smith & Zelaznik, 2004). In order to compute the variability indices (this was automatically done by the MATLAB analysis program), the time and amplitude normalized trajectories for a production were superimposed on one another, and standard deviations of movements were computed at 2% time intervals. The resulting standard deviations were summed to obtain a variability index. The lower lip/jaw variability index was computed for lower lip/jaw movements (the two are combined because it is difficult to separate lower lip movement from jaw movement when analyzing data from this marker). The lip aperture variability index was computed using the lip aperture trajectories (which were mathematically derived by the MATLAB program, through point-by-point subtraction of the upper lip movement signal from the lower lip movement signal; Sasisekaran et al., 2010). The higher the variability index, the less consistent repeated productions of the same word or sentence are (Sasisekaran, et al., 2010). (Movement duration was also obtained for sentences and nonwords via the MATLAB program.) Both lower lip/jaw, and lip aperture variability were used because the two have different variability. That is, as a result of synergistic function the lower lip and jaw have more variability to allow for better over all performance (Smith & Zelazink, 2004).

Statistical Analysis

Because of the unbalanced samples in the high vs. low contact groups, and the small sample sizes in both groups (and especially the high contact group), only limited statistical analyses were completed on this data set. Rather, descriptive statistics were analyzed and plotted to study patterns noted within the data in order to inform future studies that expand upon the current methodology used for the exploration of similar questions.

Results

Reaction Time

Average reaction times for the sentence “buy Bobby a puppy” and for the sentences of varying length and complexity are summarized in Table 8, and are plotted in Figure 1. An independent sample t-test was completed to assess if participants in the two groups differed from each other in baseline reaction time as measured for the sentence, “buy Bobby a puppy”. Visual comparison of reaction times for the baseline sentence (as seen in Figure 1) would tell us that because of the means and standard deviations, the performance between the two groups are roughly the same. Indeed, this is confirmed by the t-test, $t(5) = .81$, $p = .45$. Statistical comparisons were not completed for the other sentences, but Figure 1 depicts patterns that suggest that reaction times are longer for all sentences relative to “buy Bobby a puppy”.

Figure 1
Mean Reaction Time in Seconds

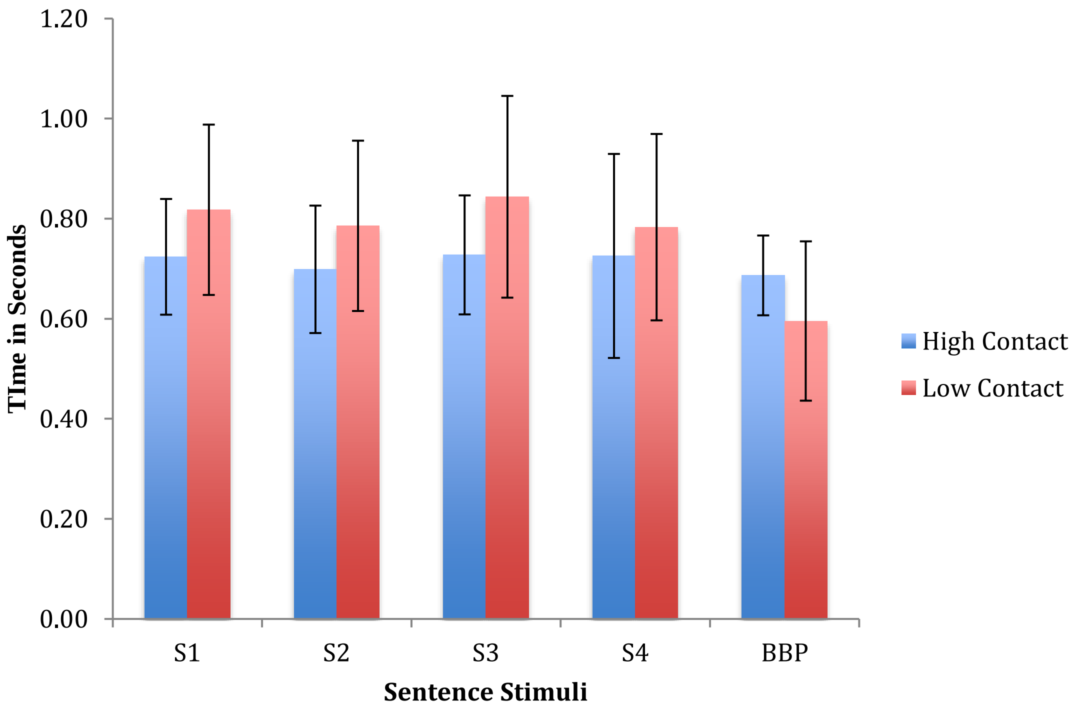

Figure 1 is a plot of the mean reaction time in seconds for the sentence task. The errors bars represent mean standard deviation for that group. For the sentences stimulus S1 corresponds with sentence one, S2 sentence two and so on respectively.

Table 8
Reaction Time Mean and Standard Deviation

	High Contact		Low Contact	
Sentence Code	Mean (In Seconds)	SD	Mean (In Seconds)	SD
S1	0.72	0.12	0.82	0.17
S2	0.69	0.13	0.79	0.17
S3	0.73	0.12	0.84	0.20
S4	0.73	0.20	0.78	0.19
Buy Bobby a Puppy	0.69	0.08	0.59	0.16

Additionally, reaction times for the low contact group appear to be slightly higher than the reaction times for the high contact group, although it is unclear if this would have been statistically different.

Behavioral data

Accuracy in the sentence task and nonword task are represented in Figures 2 and 3 respectively. Accuracy for “buy Bobby a puppy” was 100% across all participants, and therefore, no differences were present between groups. As seen in Figure 2 and Table 9, participants in both groups demonstrated high degrees of accuracy in sentence production. The low contact group demonstrated higher accuracy compared to the high contact group for all sentences except S3. S3 “The birds that saw butterflies played by the pond” was a short complex sentence, it had nine words compared to the long sentences that had 11, and had a relative clause making it complex (Kleinow & Smith, 2006). As evident in Figure 3, Table 10, the participants in the high contact group produced all nonwords more accurately on average than the participants in the low contact group. Additionally, the high contact group demonstrated lesser variability in nonword accuracy compared to the low contact group. Both groups had the lowest accuracy for nonword /mæbskrisploystrub/ and had the highest accuracy for nonword /mæbʃeɪb/. Comparison of both figures reveals that within a group, participants demonstrated higher accuracy for the production of sentences compared to nonwords. While the most difficult sentence (S4) had accuracy scores that ranged from 98% to 100% , the most difficult nonword (NW5), had scores that ranged from 65.67% to 93.67%.

Table 9
Sentence Accuracy (% Words Correct) Mean and Standard Deviation

	High Contact		Low Contact	
Sentence Code	Mean	SD	Mean	SD
S1	98.17	0.71	99.27	1.06
S2	99.33	0.94	99.73	0.37
S3	99.67	0.47	99.00	1.25
S4	99.00	1.41	99.73	0.37

Table 10
Nonword Accuracy (% Phonemes Correct) Mean and Standard Deviation

	High Contact		Low Contact	
Nonword Code	Mean	SD	Mean	SD
NW1	100	0	96.47	5.12
NW2	95.5	4.95	91.93	8.53
NW3	96.67	0	95.2	3.66
NW4	97.5	1.18	84.2	8.12
NW5	91.33	0	81.27	11.34

Figure 2
Mean Percent Accuracy Sentences Task

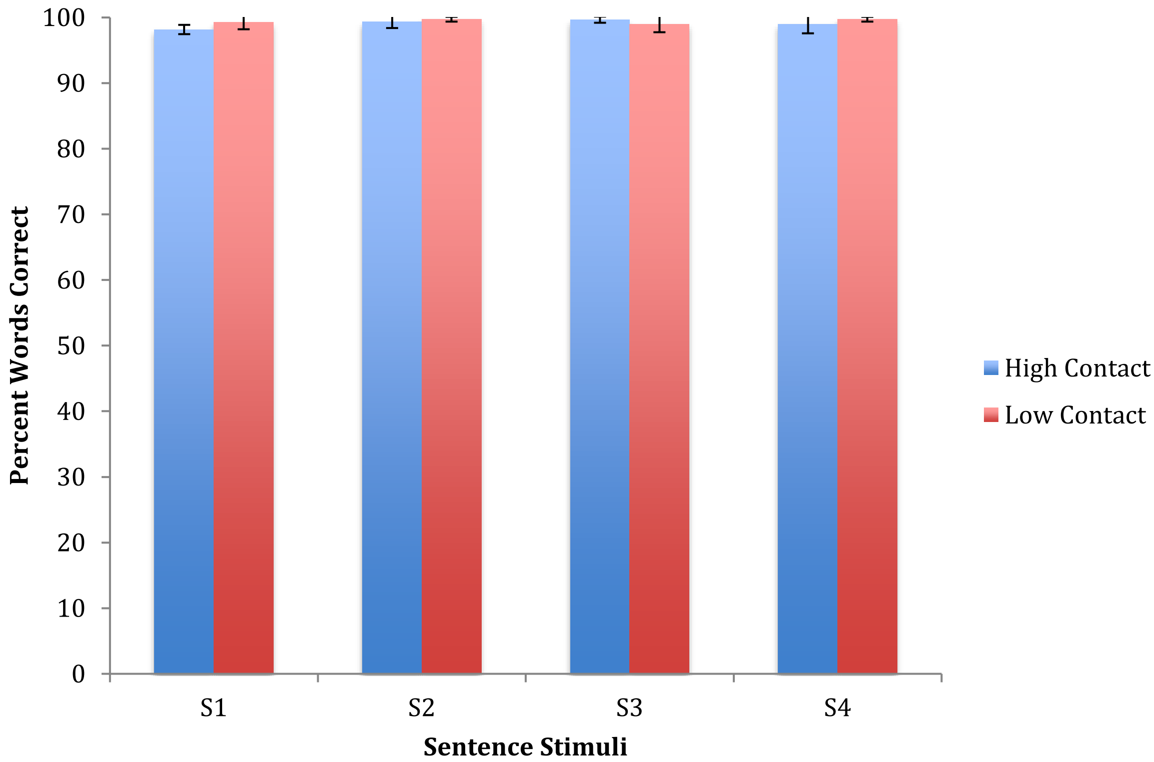

Figure 2 is a plot of the mean percent accuracy for the sentence task. The errors bars represent mean standard deviation for that group. For the sentences stimulus S1 corresponds with sentence one, S2 sentence two and so on respectively.

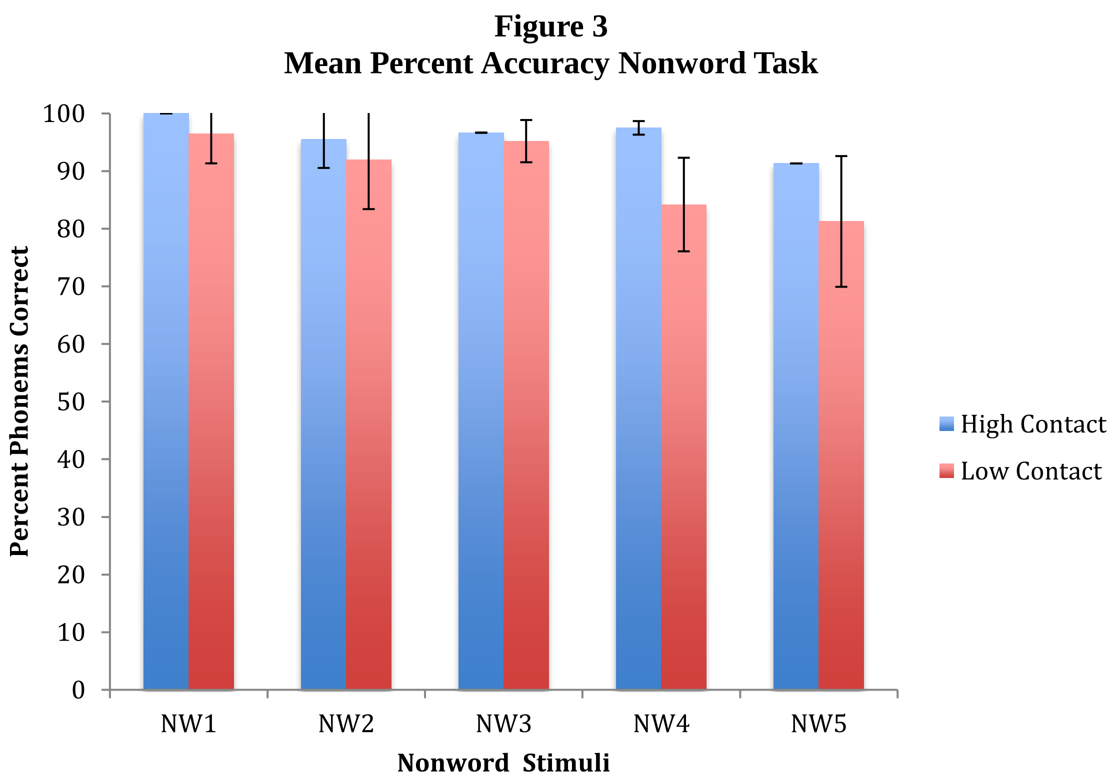

Figure 3 is a plot of the mean percent accuracy for the nonword task. The errors bars represent mean standard deviation for that group. For the nonwords, NW1 corresponds to the first nonword /mæbʃeɪb/, NW2 to /mæbfɑɪʃeɪb/ and so on respectively.

Speech Rate and Kinematic Variables

Speech Rate

The results for the reading task displayed in Table 11 indicate that the mean accuracy during reading was the same between groups. The speech rate for the experimental reading task was higher than the reading fluency task across participants. Speech rate data for the reading fluency task is included in Table 5. The mean accuracy did not vary substantially between the experimental reading task and the reading fluency task. There was a difference of 1.5% between the two for the high contact and 0.6% for the low contact group.

Movement Durations

Figure 4 and Figure 5 depict the mean duration of nonwords and sentences. In Figure 4, it is observed that the mean duration for “mabshaib” (NW1) is roughly the same for both groups. Generally speaking, mean duration increased for both groups as the nonwords became longer and more complex. However, examination of the data reveals that the increase in duration as a function of length and complexity of nonwords was greater for the low contact group vs. high contact group. In other words, as evident in Figure 4, as the nonwords become longer and more complex, both groups become slower, but the slowing is more pronounced for the low contact group. For the sentence task, there were no patterns of difference in duration between the two groups as seen in Figure 5. “Buy Bobby a puppy” was associated with the shortest durations for both groups and S2 and S4 were associated with the longest duration for both groups. S2 and S4 were both the most long sentences out of the four. Both groups demonstrated a complexity effect such that as sentence length and complexity increaesed, duration increased.

Variability Indices

In Figure 6, variability indices are plotted for the LL+Jaw as well as for the lip aperture trajectories for nonwords. The low contact group demonstrated higher variability indices (LL+Jaw and LAVAR) compared to the high contact participants for most of the nonwords (except for the most complex nonword). Another interesting pattern evident from the Figure 6 is that the low contact group demonstrated mean variability scores that didn't vary much across nonwords, whereas the high contact group demonstrated a steady increase in variability with increased nonword length and complexity.

Additionally, it is evident that the LL+Jaw and lip aperture variability indices are very similar across the simple nonwords for the high and low contact groups. For the most complex nonword, a divergence between the LL+Jaw and LAVAR indices is noticed (with LAVAR indices being higher than LL+Jaw indices).

A somewhat opposite pattern was true for sentences. The variability indices are not that different for the two measures across both groups as depicted in Figure 7. Additionally, movement variability is relatively low for the simple sentence "buy Bobby a puppy" and does not differ between the groups for either the LL+Jaw variability measure or the LAVAR measure. As sentences become longer and more complex, mean variability scores diverge for the groups such that the high contact group has higher variability indices for both the LL+Jaw measure and the LAVAR measure relative to the low contact group. Table 12 and Table 13 report the data from Figures 4, 5 and 6 in table format.

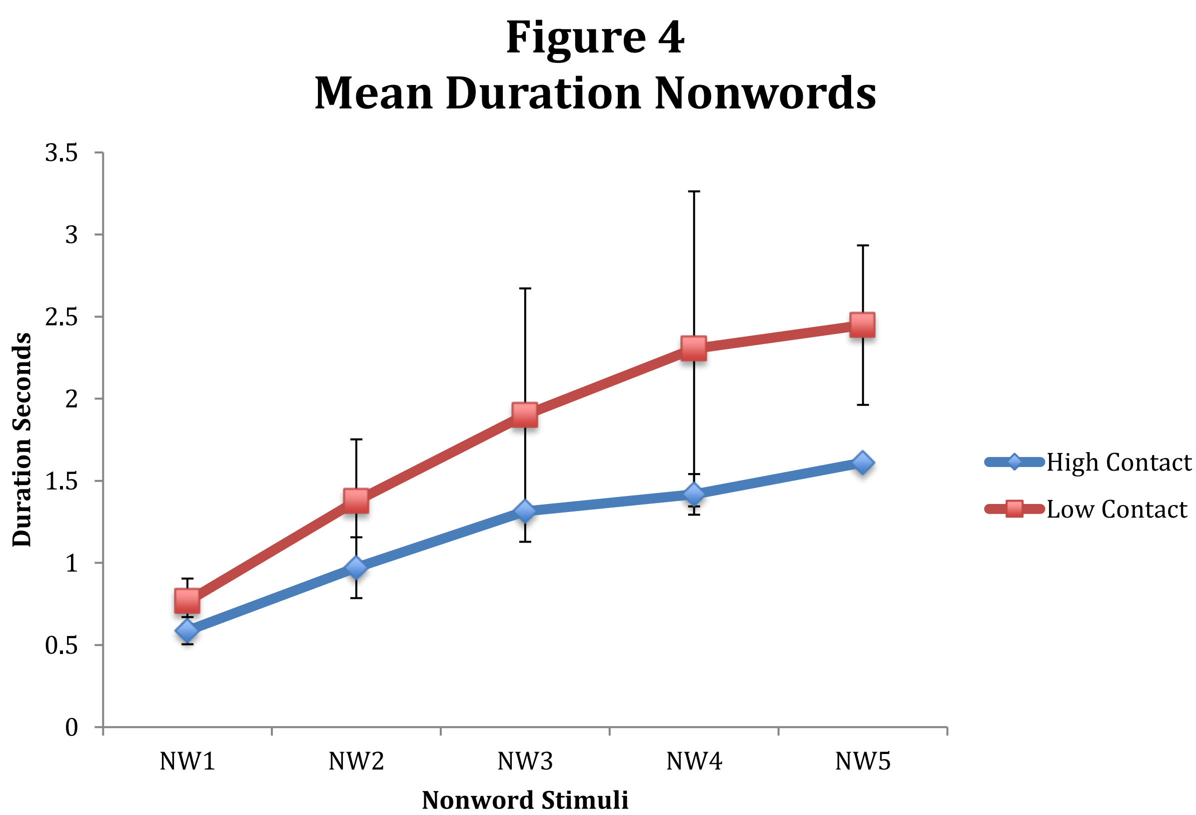

Figure 4 is a plot of the mean duration for sentence and nonwords. The errors bars represent mean standard deviation for that group. For the nonwords NW1 corresponds to the first nonword /mæbʃeɪb/, NW2 to nonword two /mæbfɑɹʃeɪb/ and so on respectively.

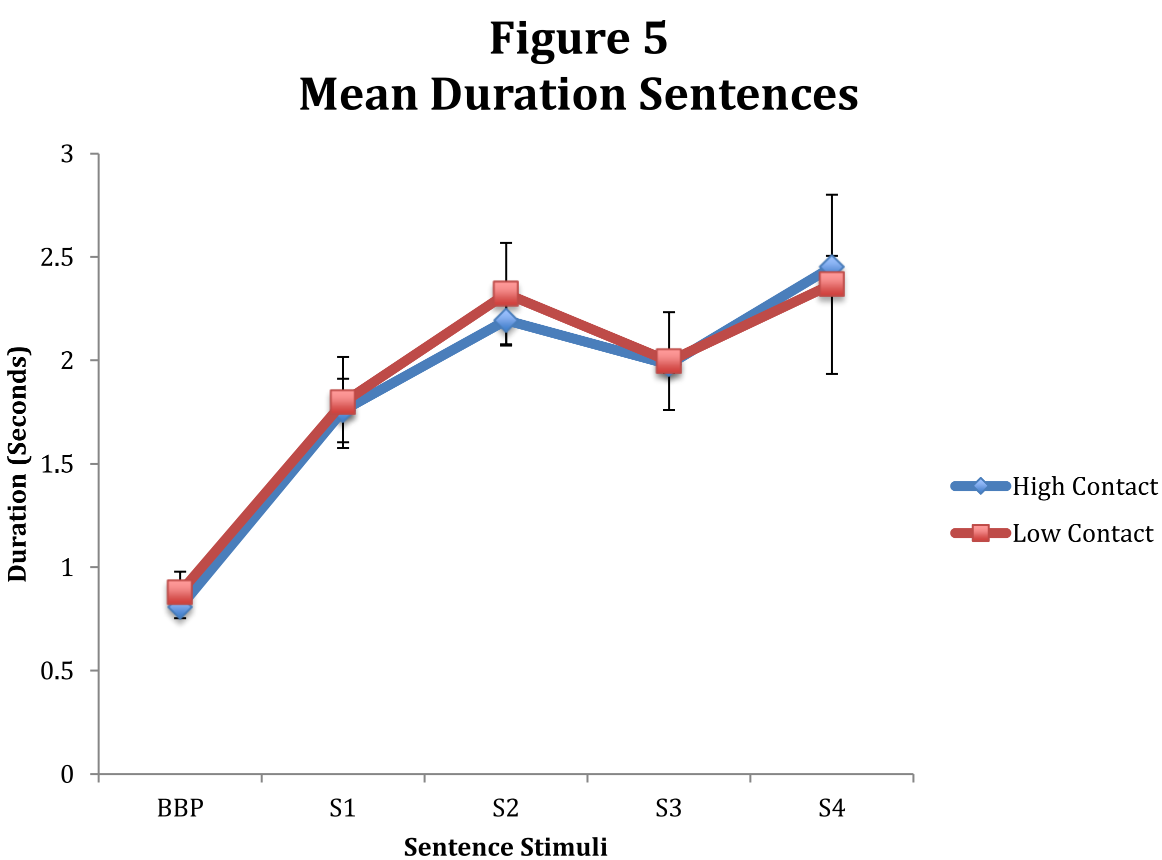

Figure 5 is a plot of the mean duration for sentence and nonwords. The errors bars represent mean standard deviation for that group. For the sentences BBP corresponds to “buy Bobby a puppy,” S1 with sentence 1, S2 with sentence 2 and so on respectively.

Figure 6
Mean LL+Jaw and LAVAR for Nonwords

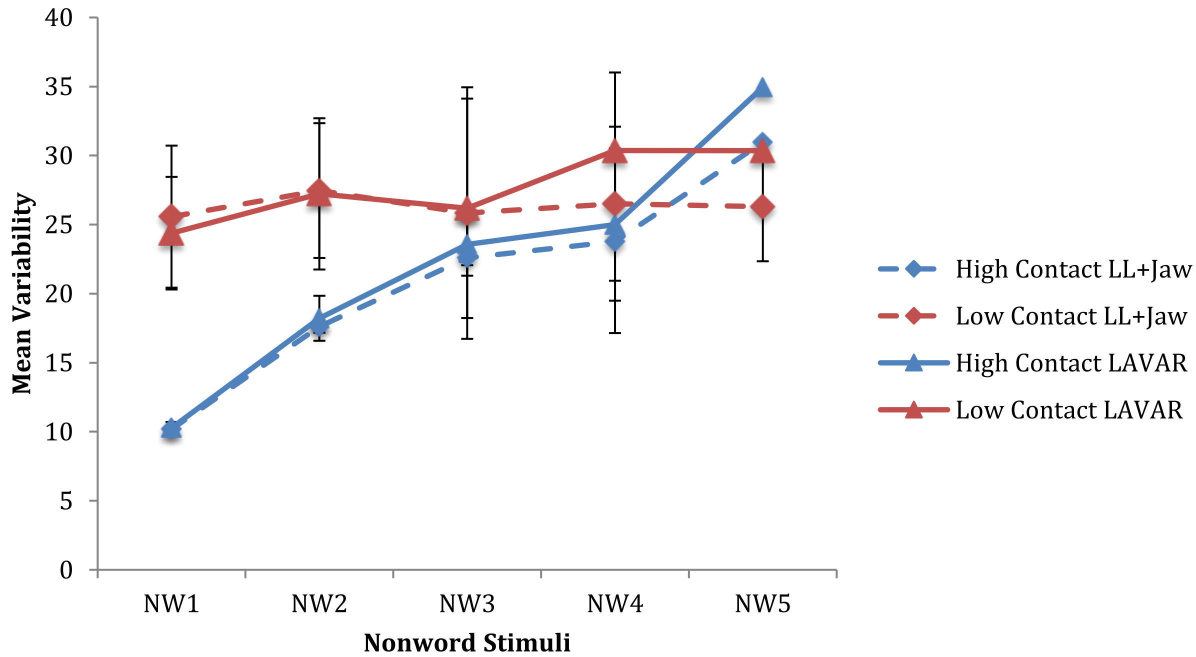

Figure 6 is a plot of the mean LAVAR and LL+Jaw for nonwords. Stimulus NW1 corresponds to the first nonword /mæbʃeɪb/, NW2 to nonword two /mæbfɑɪʃeɪb/ and so on respectively. The errors bars represent mean standard deviation for that group.

Figure 7
Mean LL+Jaw and LAVAR for Sentences

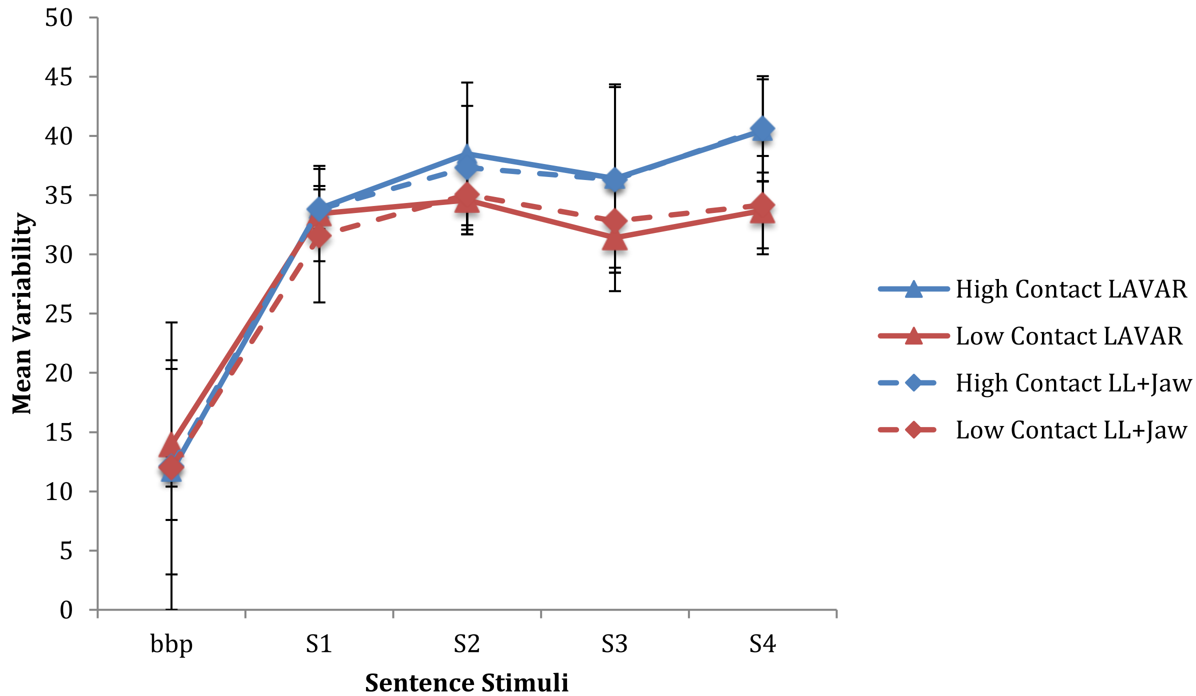

Figure 7 is a plot of the mean LL+ Jaw and LAVAR for sentence. The errors bars represent mean standard deviation for that group. For the sentences stimuli bbp corresponds to "buy Bobby a puppy," S1 with sentence 1, S2 with sentence 2 and so on respectively.

Table 11
Reading Task Accuracy and Speech Rate

Accuracy and Speech Rate per Minute				
Contact	Accuracy (In percent words correct)		Speech Rate (In words minute)	
	Mean	SD	Mean	SD
High	98%	0	216.08	3.57
Low/No	98%	3.27	201.42	14.53

Table 12
Sentence Task Data

Sentence Task: Duration				
Stimuli	High Contact		Low/No Contact	
	Mean (In Seconds)	SD	Mean	SD
Buy Bobby a Puppy	0.807	0.05	0.88	0.10
S1	1.76	0.15	1.79	0.22
S2	2.19	0.12	2.32	0.25
S3	1.98	0.04	1.99	0.24
S4	2.45	0.05	2.37	0.43
Sentence Task: Lip Aperture Variability				
Stimuli	High Contact		Low/No Contact	
	Mean	SD	Mean	SD
Buy Bobby a Puppy	11.67	1.27	13.96	6.37
S1	33.88	1.89	33.45	4.02
S2	38.49	6.02	34.59	2.88
S3	36.41	7.94	31.39	4.50
S4	40.47	4.32	33.71	3.19
Sentence Task: LL+Jaw Variability				
Stimuli	High Contact		Low/No Contact	
	Mean	SD	Mean	SD
Buy Bobby a Puppy	12.13	12.13	12.03	9.04
S1	33.82	1.67	31.58	5.63
S2	37.32	5.22	35.05	3.35
S3	36.29	7.84	32.83	3.95
S4	40.62	4.43	34.16	4.15

Table 13
Nonword Duration, LAVAR and LL+Jaw

Nonword Task: Duration				
Stimuli	High Contact		Low/No Contact	
	Mean	SD	Mean	SD
NW1	0.59	.08	0.76	0.14
NW2	0.97	0.19	1.38	0.38
NW3	1.31	.02	1.90	0.77
NW4	1.42	0.12	2.30	0.96
NW5	1.611	N/A[1]	2.45	0.49
Nonword Task: LAVAR				
Stimuli	High Contact		Low Contact	
	Mean	SD	Mean	SD
NW1	10.28	0.43	24.38	4.08
NW2	18.22	1.63	27.23	5.48
NW3	23.56	2.26	26.18	7.95
NW4	24.99	5.51	30.37	5.65
NW5	34.94	N/A[2]	30.36	1.79
Nonword Task LL+Jaw				
Stimuli	High Contact		Low Contact	
	Mean	SD	Mean	SD
NW1	10.19	0.17	25.58	5.14
NW2	17.61	0.44	27.47	4.88
NW3	22.59	0.54	25.83	9.11
NW4	23.79	6.64	26.51	5.58
NW5	30.965	N/A[3]	26.2966	3.949802

Discussion

This study set out to assess an experimental protocol that would discover patterns in stimuli that may be indicative of kinematic, and behavioral changes in athletes in high contact

[1] The first participant in the high contact group did not produce NW5, therefore there is no standard deviation for fifth nonword.
[2] The first participant in the high contact group did not produce NW5, therefore there is no standard deviation for fifth nonword
[3] The first participant in the high contact group did not produce NW5, therefore there is no standard deviation for fifth nonword

sports versus no/ low contact sports. This study examined participants in two groups: participants of high contact sports and participants of low/no contact sports. Within the time frame, recruitment of sufficient participants to find statistically significant results was a challenge. Potential participants who initially expressed interest didn't always follow through with participation in the study. Thus, the strategy taken with the seven athletes that participated was to analyze descriptive data and visually examine patterns that emerged. Because of the small sample size and limitations of analyzing only descriptive data, the results are interpreted very cautiously. While some speculations about findings follow in the next sections, a focus is maintained on methodology and suggestions for future studies. Group differences in performance as a function of contact were still examined.

As mentioned above, group differences are cautiously interpreted given the unbalanced design and small sample size. Recall that it was initially hypothesized that participants in the high contact group would demonstrate scores consistent with poorer motor performance relative to participants in the low contact group, reflective of repeated subconcussive blows (Johnson et al., 2014).

The patterns in the descriptive data indicated that the high contact group ($n = 2$) demonstrated : a) shorter reaction times than the low contact group for sentence production; b) higher accuracy scores for nonword production, c) shorter nonword production durations and an increase in duration with increased nonword length and complexity that was not as pronounced as that noted for the low contact group, d) higher variability indices compared to the low contact group for sentence production (especially complex sentences), and e) lower variability indices compared to the low contact group for nonword repetition (especially simple nonwords).

Indeed, the above patterns for nonword production indicate that, generally speaking, participants in the high contact group are performing better than participants in the low contact group with a few exceptions. While this may be an artifact of the small sample sizes and should be interpreted with caution, it is nevertheless an interesting trend. This trend was found in a recent study of nine ice hockey and football players. The cohort in this study, which was exposed to subconcussive events, did not perform worse than the control group like expected, but outperformed the control in an ImPACT battery in visual motor speed and reaction time (Belanger et al., 2016). These findings might indicate that subconcussive events do not necessarily result in adverse effects. In fact, it maybe be speculated that effects are potentially neuroprotective. That said, the Belanger et al. study relied on self reporting the level of subconcussive blows endured by the athletes, therefore making it difficult to arrive at the conclusion that athletes who endured more subconcussive events indeed outperformed their counterparts in low contact sports. The sample size in both the Belanger et al. study and the present study also make it difficult to come to the conclusion that subconcussive events may be neuroprotective. Neither cohort had a large enough pool of participants to find statistically significant data. It is possible that the patterns observed are simply artifacts of unbalanced groups and small sample sizes in the present study. Future studies should utilize much larger sample sizes with a balanced group design.

The theory that subconcussive blows are neuroprotective is not supported in most literature. Tsushima et al. (2016) found lengthened reaction times and processing speeds in athletes in high contact sports. Furthermore, Virgilio et al. (2016) noted acute changes in corticomotor function and memory function in soccer players who were routinely involved in heading. And though outside the scope of this study, physical changes in the white matter of the brains of athletes who participate in high contact sports have been noted previously in neuroimaging studies (Belanger et al., 2016). There is an overwhelming trend in current literature that repetitive subconcussive events are detrimental to an athlete's cognition and even structural and functional integrity of the brain. Even if disadvantageous trends aren't found in data collection, such as no differential results in the overall ImPACT score in the Tsushima et al. (2016) study, the general trend in literature is that repetitive impact to the brain most likely hinders performance and does not help.

In the current study, findings relating to reaction time were interesting. It might be expected that reaction time would be longer in the athletes in the high contact group based on the findings of decreased efficacy of processing speed and reaction time reported by Tsushima et al. (2016). However, as observed in the ImPACT test reduced processing speeds would explain longer reaction times were reported. However, this was not the trend observed in the current study; rather, shorter reaction times for athletes in high contact sports. Again while it is plausible that subconcussive events aid reaction time, there is not sufficient current literature to support this at this time.

The findings pertaining to speech rate and movement duration were particularly interesting. Most previous studies of speech in individuals with documented brain injuries list speech slowing as a hallmark characteristic of injury (Bough et al., 2012). Therefore, it was expected that participants in the high contact group would demonstrate slower rates of speech and longer movement durations relative to participants in the low contact group. In the current study, the rate of the reading passage did not show any substantial differences between the groups. This was unexpected; when applying Johnson et al.'s (2014) finding of reduced motor attention in individuals who play high contact sports, for example, it would be logical that speech rate would go down. The patterns for duration as they pertain to nonwords, in particular, are worth considering more carefully. As linguistic load (length/complexity) increased, it was the low contact group that demonstrated disproportionate increases in nonword production duration relative to the high contact group. This was an unexpected finding based on the literature (Kelinow et al., 2006). An initial speculation may be that the low contact group slows more in order to achieve a higher degree of accuracy in nonword production. However, this was not the case; the high contact group demonstrated higher nonword accuracy scores compared to the low contact group. Similarly, the high contact group was less variable in their movements compared to the low contact group for nonword production, evidencing a higher degree of precision. This might be the result of the small high contact group sample size.

The sentence task, on the other hand, elicited a more expected pattern in results, with the high contact group demonstrating higher LL+Jaw and LAVAR indices compared to the low contact participants for sentence production. The connection between Johnson's motor attention seem to be applicable in the sentence task. The disparity between groups in variability indices during the sentence task could imply that motor planning has been affected in athletes in high contact sports like it was in the study Johnson et al. conducted looking at fMRIs (Johnson, Neuberger, Gay, Hallett, & Slobounov, 2014). Both groups had similar baseline performance for their production of "buy Bobby a puppy," but the deviation became evident even at the first sentence. This would be expected considering Johnson et al's (2009) findings of reduced motor attention in athletes who endure repetitive subconcussive events (i.e., the high contact group). This reduced motor attention might be the cause of increased variability for the high contact group relative to the low/no contact group within the sentence stimuli. The understanding of motor degeneration associated with CTE and alterations in motor attention in current athletes in contact sports makes the speculation that motor processing or execution could be reduced in this cohort of athletes in high contact sports compared to athletes low/no contact counterparts a feasible one. There is no evidence that the mode of stimuli for the sentences (visual) would effect the outcomes of these results. Virgilio et al. (2016) establishes this by finding visual processing speed is not affected in soccer players that experienced exposure to subconcussive events.

The patterns seen in the movement graphs represent two things. That is, variability doesn't increase by much from the easiest to the most complex nonword for the low contact group. On the other hand, high contact group demonstrated improved consistency of repeated movements of simple nonwords compared to the low/no contact group, but also showed a more dramatic increase in variability as nonwords became longer and more complex. A similar pattern is noted for LL+Jaw variability. This could be due to the change in cognitive load. With the simpler, less cognitively demanding stimuli, it was possible to have less variability but as cognitive load increased, so did the variability. Athletes in the high contact group, therefore, may be more susceptible to changes of more complex cognitive loads than the athletes in the low/no contact group.

Effects of stimuli varied but generally speaking, for the sentence and nonword tasks, a sensitivity across stimuli was observed. The descriptive statistics in the nonwords display a pattern that differs from the pattern in the sentences. The first large discrepancy is that the groups do not coincide with each other on the variability indices for the production of NW1 /mæbʃeɪb/, but NW3, /mæbʃeɪtɑɪdɔɪb/, and NW4, /mæbspoʊkwifleɪb/yield more similar results across groups. This contradicts the report that there is consistently more variation in movement with complexity that was inferred from the Sadagopan (2008) article. Thus, these differences based on complexity are not always predictable and may be influenced by individual- or group- specific factors.

The sentence stimuli possessed consistency across studies making them dependable stimuli to used in future studies. In the study conducted by Kleinow et al. (2006) that looked at movement variability in increasingly complex sentences, movement variability increased in a consistent and predictable way as the stimuli increased in length and complexity. That trend was corroborated in the present study as the variability increased for all participants as stimuli got longer and more complex. Deviations were found in movement variability that could be due to alteration in motor processing or execution caused by repetitive subconcussive events. This conclusion can be drawn by applying the finding of alteration in motor attention in the study conducted by Johnson et al. that used neuroimaging to find reduced motor attention in athletes in high contact sports (2014) to this study. A definite connection cannot be drawn between these two studies due to the differences in methodology. However, inferences can be drawn when taking into account the fact that both studies examined groups of participants in high contact sports and also when considering the long term alterations in motor performance in retired athletes who have been diagnosed with CTE (Bough et. al., 2012).

Because the differences noted in group performance between the two types of stimuli demonstrate inconsistent patterns, there are methodological considerations that should be addressed. First, as mentioned several times in the discussion, recruiting a larger sample size of participants is critical in future studies. While there are some interesting patterns that are evident from the present study, no conclusions can be made with confidence. Secondly, it might be beneficial to present all stimuli in the same mode. This would reduce any variation that might be related to modality differences. Having stimuli all aurally presented (like the nonwords in the present study), might be the best solution to this methodological issue, but poses the potential challenge of taxing auditory short-term memory ability of participants who may be especially susceptible to changes in cognitive-motor function. Finally, a future study might also consider having the participants come in for two assessments of the nonword task and the sentence task to see if there are any alterations in how athletes learn based on their exposure to subconcussive events.

Conclusion

This exploratory study examined patterns within- and across-groups in seeking answers to the question “do individuals who participate in high vs. low contact sports differ from each other in parameters of speech production?” The common trend in the descriptive statistics were that complexity changes in stimuli produced obvious effects on several parameters of speech production, and elicited differences between groups, especially in performance on longer and more complex productions. It appears that participants who were subject to a greater number of impacts (high contact sports) and were therefore more susceptible to subconcussive changes, demonstrated increasingly detrimental performance as length and complexity increased in some cases, but not in others. Few differences between groups were reported, overall, and this is at least in part due to challenges in making comparisons between unbalanced, small groups. Nevertheless, the patterns that did emerge via this research revealed, in several instances, that the high contact group outperformed the low contact group. This finding is unexpected and these patterns would benefit from further examination in future studies.

The effects of subconcussive events on athletes in high contact sports are an important and current topic that should be addressed in future studies. The effects of repetitive subconcussive events effects span beyond just speech and cognition. But understanding these subtle changes that might be happening in athletes brain is a small yet important piece of the continually growing puzzle of the consequences of contact sports.

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