

Will Strengthening the Cervical Muscles of the Neck Diminish the Risk of Concussions?

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Nathan Bull

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THE COLLEGE AT BROCKPORT  
STATE UNIVERSITY OF NEW YORK  
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Department of Kinesiology, Sport Studies, and Physical Education

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Diminish the Risk of Concussions?

Read and Approved by: \_\_\_\_\_  
Francis M. Kozub, PhD

Date: \_\_\_\_\_ April 26, 2015 \_\_\_\_\_

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Date: \_\_\_\_\_

\_\_\_\_\_  
Dr. Cathy Houston-Wilson  
Interim Chairperson, Department of  
Kinesiology, Sport Studies, and Physical  
Education

## Abstract

Recent research has postulated that strengthening the muscles surrounding the head-neck vertebrae may help minimize the risk of concussion in football. Although no study has confirmed that stronger and larger neck muscles will minimize football related concussions, nevertheless sport practitioners have incorporated a wide array of strength training protocols focused on strengthening this area in an attempt to dissipate the force of an impact away from the brain. The purpose of this synthesis was to examine if a critical mass of literature supported the perception that stronger and larger neck muscles facilitate the attenuation of impact forces to the head thus minimizing the risk of concussion. The studies reviewed within the critical mass of this synthesis related to neck strength and the diminished risk of concussion in sport failed to support this direct correlation. However a number of studies indirectly showed that cervical musculature can minimize several risk factors of concussions such as head impact angular, rotational and linear acceleration. Additionally it was deduced that neck stiffness or muscle activation upon impact rather than cervical size and strength alone may be the greatest contributor to the dissipation of forces to the head upon impact. This information provides a better understanding of the risk factors associated with a concussion and how an athlete's cervical anatomy is affected and can affect the onslaught of a concussive force. More research is needed to study the best strength training strategies possible as well as if and how polymeric training rather than isotonic resistance training improves the cervical musculature responses to a traumatic head impact and eliminate the risk of concussion.

*Keywords:* [Concussion, Cervical strength, Neck stiffness, Football,]

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## Chapter 1

### INTRODUCTION

Concussions have become one of the most significant injuries plaguing a wide variety of sports and age levels all across the nation. Various sports, individual playing styles, positions, and level of play all affect the risk of concussion (Harmon et al., 2012). Additionally sport related concussions have the potential to pose both short and long term aversive effects to the cognitive functioning of injured persons (Guskiewicz et al., 2003). It has been recognized that sport related concussions are often caused by impacts to the head or body that transmit forces to the brain initiating it to shift within the skull. Due to the large number and wide range of age groups participating in football across the country and the high rate of impacts per practice and contest, football has become the most observed sport in regards to studying the causes, effects and tendencies of sport related concussions. Although there is no way to accurately indicate the total number of sport related concussion incidences within the United States, it is estimated by the Centers for Disease Control and Prevention that upwards of 3.8 million concussions occur annually with around 300,000 considered to be sports related (Guskiewicz & Mihalik, 2011). Due to the risks associated with sport related concussions, prevention of sport related concussions has become a priority for athletic trainers, coaches, athletes and other sport practitioners alike.

#### **Background Information**

Initial consequences of concussions include an onset of brief impairment of neurological functions that generally settles spontaneously and can at times result in a loss of consciousness as well as impaired mental status (McCrory et al., 2012). Often the terms concussion and mild traumatic brain injury (mTBI) are used interchangeably to describe this particular brain injury.

Rather than a structural change like many sport related injuries, acute symptoms of sport related concussions tend to simply result in a functional disturbance of the brain while also creating symptoms such as headaches and dizziness (Signoretti, Lazzarino, Tavazzi, & Vagnozzi, 2011). Reported long term effects include serious neurological deficits as well as Chronic Traumatic Encephalopathy. Risks of these effects which result in depression, impulse control complications, and memory loss are often heightened when receiving multiple concussions throughout a lifetime and/or neglecting to properly rest or treat a sport related concussion (Minnesota Epilepsy Group, 2012). Although some long term effects are still unknown, a large emphasis has been placed on searching for a better understanding of the side effects of concussions.

To date, research has focused on both establishing a diagnosis and the management of concussion symptoms; however, little research exists on preventative measures. A wide range of symptoms accompanying a concussion have been thoroughly studied and placed into universal grading systems to help better detect, diagnose, and record the occurrence of a concussion (Marshall, 2012). Marshall identifies some of these grading systems which include the Balance Error Scoring System (BESS), Sideline Concussion Assessment Tool and the Standard Assessment of Concussion (SAC) (Marshall, 2012). As the detection of concussions in sport has improved so has the ability to manage these injuries. From a short term perspective medical care providers have improved the return to play guidelines and handling of these injuries until symptoms have subsided however much more research is needed to understand how to manage the long term effects of these injuries (McCrorry et al., 2013). Proactive strategies for sport related concussion prevention that are being employed include the improvement of equipment, educational efforts and the proposal of rule changes to minimize concussive impacts to the head.

While strength training programs have been proven to help reduce upper and lower limb injuries, little is known about the effect of strength training techniques on the cervical muscles and the deterrence of sport related concussions (Benson et al., 2013).

The 4th International Conference on Concussion in Sport has reported that there is currently no substantial evidence that supports the theory of improved neck strength and a decreased incidence of sport related concussion (McCory et al., 2012). However Schmidt et al. (2014) identify cervical muscle strength as a possible component of the stabilization of the head and also indicate that it may play a large role in the absorption of impacts and reduction in the instance and severity of concussions. With this information it is necessary to discover any correlation between cervical musculature and the minimizing of sport related concussions in athletes.

### **Nature of the Synthesis**

The purpose of this paper is to synthesize the literature to determine if evidence exists that increased training to strengthen the muscles used to assist in the stabilization of the head and neck will help to improve the ability to absorb concussive impacts which will in return minimize the number of reported concussions within intercollegiate football. Additionally it will be necessary to find if the critical mass of literature supports the relationship between neck strength and size and to determine if these factors can assist in the dissipation of force to the brain as a result of an impact. There is an overall lack of research on strength training routines aimed to improve cervical musculature and diminish the incidence of concussion in intercollegiate football athletes. However a number of studies have examined the relationships between concussions and specific demographics, location of impacts and concussion incidences, force of impacts or thresholds that result in concussions, biomechanics of the impact as well as neck

stiffness and the frequency of concussion. These studies will be examined along with an attempt to determine if there are mediating variables such as player awareness that can impact on concussion related outcomes in contact sports. Finally, recommendations will be constructed for use by sport practitioners to utilize with their athletes in a setting that promotes the physical and athletic improvement of collegiate football players.

### **Summary**

The issue of concussions in football continues to be a growing concern for athletic trainers, coaches, athletes and fans alike due to the increased understanding of both short and long term effects of this mild traumatic brain injury. As athletes become bigger, stronger and faster the collisions inherent in the game of football become much more frequent and violent. Preventative measures such as equipment improvements and rule changes have attempted to address the problem; however there is consensus that more needs to be done and training that helps reduce concussions is one avenue to address the problem. Many individuals in the field of strength and conditioning have begun to experiment with and implement training programs for the neck and surrounding muscles in order to improve stabilization as well as the absorption of impacts. In theory it is believed that implementing these different strength training techniques will diminish the incidence of concussion among intercollegiate football players. The following sections provide the synthesized findings of the research mass most closely related to understanding how strength training can affect the incidence of concussion as well as additional information and recommendations to be used by fellow sport practitioners.

## **Chapter 2**

### **METHODS**

The information compiled in this synthesis encompasses literature relating to the biomechanics of a sport related concussion, the role of cervical strength and neck muscle size on the prevention of sport related concussions is the focal point of this literature search. The information sought resulted from searching multiple electronic databases including ScienceDirect and EbscoHost. When searching these electronic databases key words such as “concussion prevention”, “concussion prevention and weight training”, “concussion prevention and strength training”, as well as “neck strength and concussion” were utilized to obtain further information about the cause of concussions and the role of cervical muscle. The search for “concussion prevention” with EBSCOHost yielded 380 results where three studies were identified as effective. Additionally EBSCOHost was searched with the key words “neck strength and concussion” and this search yielded another 13 results, four of which were considered useful.

#### **Search Procedures**

Key words including “concussion prevention and weight training”, and “concussion prevention and strength training” had very minimal results and no literature suitable for answering the question regarding the ability of strength training methods being able to reduce concussions was found. However 15 of the studies identified provide suitable information regarding the biomechanics of the neck during a blow to the head, the forces experienced when receiving a concussive blow, the effect of muscle strength on impact absorption and anticipatory activation of the cervical muscles during a concussive impact. All of this information is useful in determining the way the head and neck respond to concussive impacts and theoretically discover

how improvements can be made to help prevent the acceleration of the head that generally causes sport related concussions.

### **Inclusion Criteria**

The inclusion criteria were developed to maximize the use of current research. Of the studies analyzed it was necessary to include articles that have been conducted and published from the year 2000 to the current date relate to concussion findings. As research has evolved along with the significance of the potential side effects of sport related concussion it is necessary to utilize up to date and current literature about the topic. Additional sources have been pulled from the reference sections of multiple studies originally selected from online databases. Although the focus of the synthesis is on determining whether or not strength training can assist in the prevention of sport related concussions, some of the studies are not restricted to sport.

### **Summary**

The following section includes results from the literature search. A critical mass of studies and some additional conceptual writing were used to examine if strength and conditioning protocols were useful in attempting to create a safer playing environment for collegiate athletes playing football.

## **Chapter 3**

### **RESULTS**

This section provides the reader with known findings concerning concussions in athletics. Specifically, a section on defining concussions developed from leading medical and academic sources is provided given the variability in the literature on concussions and related conditions. This includes sections that provide data based studies on the biomechanics and the pathophysiology of concussions. This is followed by discussions on the short term effects of concussions, post-concussion vulnerability, concussion in sport, and the information that points to neck training that may impact on the incidence of concussions.

#### **The Nature of Concussions**

Over the past several decades the definitions for concussions have continuously evolved as research has become more abundant and detailed. During the mid-1960's the Committee on Head Injury Nomenclature of Neurologic Surgeons defined a concussion as “a clinical syndrome characterized by the immediate and transient posttraumatic impairment of neural function such as alteration of consciousness, disturbance of vision or equilibrium due to brain stem dysfunction” (Lovell, 2009, p. 331). Much of this definition is still taken into consideration when describing concussions however this definition has been reduced for more efficient use in the world of sport science. Concussions are now often described as mild traumatic brain injuries and both terms are repeatedly used interchangeably to specify the injury.

Current thinking on concussions include findings from the most recent 4th International Conference on Concussion in Sport defines a concussion as a pathophysiological process affecting the brain induced by traumatic biomechanical forces (McCrory, et al. 2013). Specifically concussions are the result of an impact force to the head or body that causes the

brain to accelerate and/or decelerate at a speed that the cerebral spinal fluid is overcome and the brain collides with the skull initiating the injury (Marshall, 2012). Signoretti et al. (2011) adds that concussions often result in the rapid onset of short-lived impairments of neurologic function which generally naturally settles itself. Many of these definitions describe injury to the brain that results in a number of symptoms both directly following the incident and up to a month or more after. As the definitions vary so do the symptoms used to diagnose the injury thus resulting in a problematic process of identifying, recording, and treating these brain injuries. Additional information regarding the detailed processes behind a sport related concussion can be further categorized into biomechanical and pathophysiological explanations. The following two sections explore concussions further from a biomechanical and pathophysiological perspective.

***Biomechanics of a Concussion.*** The way in which the head and neck react to a forceful impact often results in how much force is delivered to the brain. It is understood that linear and rotational head accelerations or deceleration due to impact are the cause for sport related concussion (Guskiewicz & Mihalik, 2011). Cameron Marshall describes a concussion as a sudden and forceful linear and/or rotational acceleration or deceleration of the head that caused movement of the brain within the skull (2012). These accelerations or decelerations are caused by either a direct or indirect impact to the head or body. Guskiewicz and Mihalik (2011) define a direct impact as a significantly forceful blow to the head while an indirect impact refers to a collision to the body that sets the head in motion with enough force to result in a movement of the brain within the skull. Benson et al adds that these impacts are characterized by a number of variables that affect the incidence of concussions. These factors include the impact location, impact force, linear, angular and rotational acceleration and head velocity (Benson et al., 2013).

Although impacts to the head and body are common in the game of football thus resulting in a greater number of concussive injuries than other sports, the body has the ability to attenuate some of the effects of the impacts as well. It is believed that individual disparity in cerebrospinal fluid, musculoskeletal strengths or weaknesses, and the anticipation of an impending impact all work as a defense mechanism against concussive impacts (Guskiewicz & Mihalik, 2011). However with enough force, linear, rotational and angular accelerations will still cause movement of the brain inside the skull and possible shearing and tensile strains within the brainstem which then lead to the more serious pathophysiological impacts following a injurious collision (Signoretti et al, 2011). Even with optimal head-neck segment stiffness, kinetic energy may still be transmitted to the brain causing injury (Guskiewicz & Mihalik, 2011).

***Pathophysiology of a Concussion.*** When a severe impact to the head or body creates linear and/or rotational forces that are transmitted to the brain an immediate initiation of complex chemical processes within the brain begin to follow (Signoretti et al, 2011). Marshall describes pathophysiology as an altered health state and/ or function of a particular process within the body generally altered by a particular injury, syndrome or disease (2012). More specifically this term has two components first of which discusses physiology of the human body and secondly the functional changes in the body due to the body's response to undesired changes. Signoretti et al. (2011) describe the process pathophysiological process of a concussion as a multifaceted series of metabolic events that create a perturbation of delicate neuronal homeostatic imbalances. Current literature indicates that concussion injuries mainly result in a metabolic ATP deficiency due to ionic imbalances generated from mechanical alterations of the affected neurons (Marshall, 2012). Levy et al. (2004) add that animal and human research has revealed disruptions in metabolic homeostasis at the cellular and molecular level. Furthermore it is stated that

throughout impact to the head and as the brain accelerates there is an abrupt mechanical elongation and shearing of neurons which may or may not lead to a brief loss of consciousness (Marshall, 2012). Specifically the ionic imbalance and altered metabolic state of the brain requires energy to restore homeostasis (Harmon, 2013). This need for energy comes at a time where cerebral blood flow is diminished and mitochondrial dysfunction takes place (Harmon, 2013).

Simply stated concussions result in neuronal dysfunction rather than cell death caused by biochemical and neurochemical alterations within the brain thus indicating often reversible functional deficit rather than definite structural damage (Marshall, 2012). Repeated concussions and receiving concussions without having fully recovered from a prior incidence can result in permanent long term affects as opposed to minor isolated occurrences.

### **Short Term Effects of a Concussion**

Directly after concussive trauma individuals tend to experience a number of different symptoms and can continue to experience them days to weeks after the injury. The Fourth International Conference on Concussion in Sport identified a number of domains that symptoms generally fall under and these include physical signs, clinical symptoms, cognitive impairments, neurobehavioral features as well as sleep disturbances (McCrory et al., 2013). Robert Cantu developed a grading scale that provided a number of symptoms to help more effectively identify a sport related concussion. Some of the indicators include the recognition of a loss of consciousness, confusion and amnesia also included are the time frames in which these symptoms are noticeable thus the longer the symptoms are felt the worse the grade of the concussion (Lovell, 2009). Signorretti et al. (2011) provide a number of short term effects that are often described post concussive impact and include headache, dizziness, blurred vision,

attention difficulty, nausea/vomiting, blurred vision, lethargy, memory problems and more.

Harmon, Drezner and Gammons (2014) published additional signs and symptoms which were broken down into four categories including physical, cognitive, emotion and sleep indicators. Many of Signorretti et al. (2011) symptoms fell under the physical indicators listed by Harmon et al. (2013) which added more specific cognitive short term effects of a sport related concussion such as feeling sluggish, a decrease in reaction abilities, difficulty concentrating, slow response rates, with additional sleep difficulties and emotional distress being other indicators.

Headaches are recorded as the most common symptom associated with concussions in athletics and signs of amnesia days to weeks following an impact are strong indicators of concussion as described by Lovell (2009). Appropriate observation and evaluation of athletes following a concussive impact leads to the ensuing steps of managing the injury and determining return to play protocols. Proper management of concussions is necessary in order to reduce the risk of the less understood long term effects of single and multiple concussive injuries to the athlete.

### **Post Concussive Brain Vulnerability**

Perhaps the most significant sport related concussion issues derive from athletes returning to play too quickly and acquiring an additional impact producing head trauma. Controversy often surrounds the amount of recovery time an athlete needs after receiving a sport related concussion. It has been stated that signs and symptoms of concussions are often alleviated within 7 to 10 days for 80-90% of those that receive a sport related concussion following a concussive impact (McCrorry et al., 2012). However an athlete being subjected to a second concussive impact without complete recovery from their initial concussion may acquire significant cognitive issues. As the side effects of a concussive impact on metabolic and energy

states of the neuronal cells in the brain subside there is often a period of vulnerability where a second impact, even of non-concussive force, may cause irreversible damage and even death to the brain's cells (Signoretti et al., 2011).

Further reports show that a history of concussions can be linked to doubling the risk of sustaining a further concussion to even creating a risk 5.8 times higher than those without a history of a previous concussion (Harmon et al., 2013). Harmon et al. (2013) reported that a number of human and animal studies support the view that an additional brain injury prior to the full recovery of the initial concussion produces a deterioration of cellular metabolic changes as well as greater cognitive deficits (Harmon et al., 2013). With post-concussion brain cells left concussed and in a state of vulnerability, sustaining a second concussive blow may lead to irreversible damage often caused by swelling within the brain. Recent research has discovered potential links between multiple concussions incidence by an athlete and the onset of neurodegenerative processes (Levy et al. 2004).

### **Concussion in Sport**

Concussions have become one of the most pronounced medical concerns within contact sports. Age, gender, prior concussion history and level of fitness all play roles in the incidence rates of concussion with certain demographics and sport participants being more susceptible to concussions than others. In a recent study of high school student athletes injury incidences were evaluated by sport and it was discovered that 13.2% of all injuries recorded were sport related concussions (Marar et al., 2012). Additional information from Herring et al. (2011) discovered that concussions account for 5% of all sport injuries, slightly lower than what Marar et al. (2012) had recorded. Other data acquired from a study of NCAA collegiate football players presented

by Guskiewicz and Mihalik (2003) found that 6.3% of all participants had received a sport related concussion.

Harmon et al. (2013) stated that female athletes and females in general have a greater likelihood of receiving a concussion and specifically in sports played by both males and females the females sustain more concussions than their male counterparts. Many studies have found that physiological differences in females such as decreased head-neck segmentation, neck size, and neck strength in different positions may cause a greater risk for receiving a sport related concussion (Marshall., 2012). Similarly younger athletes such as youth and high school sport participants generally have a greater risk of receiving a sport related concussion than their collegiate and professional counterparts for similar physiological reasons (Harmon et al., 2013). It is necessary to understand the concussion rates as well as the patterns of injuries associated with each sport and demographic to improve the targeting of preventative measures such as strength training programs for athletes.

Marar et al. (2012) reported that in gender-comparable sports females have a higher incidence of concussion as compared to males furthermore concussions represent a higher proportion of sport related injuries in sports played by females. Additionally Marar et al. (2012) also agree that this higher incidence rate is possibly due to biomechanical differences in the head and neck of females. American football has received the largest amount of attention in the media and throughout studies in regards to concussion identification, management, treatment and prevention. Rule changes at all levels as well as helmet upgrades and tackling technique modifications have all been generated in an effort to lessen the number of concussions for all participants (Benson et al., 2013). Through research many concussion incidence tendencies have been recognized in the sport of football. Player position can often affect the number of impacts a

player receives as well as the average force of the impacts can be easily recorded and ranked for each player (Crisco et al., 2010). Levy et al adds that game speed, field surface composition, weather, individual style of play, differences in player physical attributes and protective equipment are additional factors that influence the rates of concussion in the game of football (Levy et al., 2004). A study performed by Crisco and others recorded the frequency and locations of head impacts that players at each position received over a collegiate football season. It was discovered that offensive lineman, defensive lineman and linebackers received the largest quantity of impacts, furthermore the overall team average of impacts to the head per game were 16 and an additional 6 impacts to the head per practice (2010). Conversely skill players such as wide receivers, defensive backs and running backs receive a lower number of impacts as compared to lineman; however this group typically experiences impacts with a greater force (Crisco et al., 2010). Overall a number of studies have been able to provide trends in the factors such as playing position, location of the impact as well as the force of the impact generally needed to induce a concussion. Crisco et al not only determined that head impacts occur three times more throughout a game than practice but it was also concluded that frontal impacts to the head made up the majority of impacts to the head for the collegiate players (Crisco et al, 2010). This data assists sport practitioners in developing preventative measures to inhibit future rates of concussions in football.

### **Role of Neck Strength and Size**

In recent studies neck strength has been considered to be a significant component in stabilizing both the spine and head-segment. Additionally the strength of the cervical muscles has also been considered an important feature in the incidence of concussion. Levy et al. (2004) mentioned player anatomy otherwise neck strength as a possible factor for the risk of concussion

in sports. Specifically shoulder and cervical musculature were identified as significant factors in maintaining head and neck alignment, or head-neck segmentation, and throughout a football related impact (Levy et al., 2004). In addition, Benson et al. (2014) postulated that increasing cervical muscle strength could help attenuate the movement of the head after impact as well as the rotational kinematics often associated with traumatic collisions thus reducing the risk of concussion. Often cervical strength has been quantified isometrically rather than dynamically. Muscle activation upon impact is an additional component of head impact biomechanics that may help to understand new means of improving the attenuation and reduction of sport related concussions. Marshall (2012) reported that awareness of an impending collision allows an individual to contract cervical stabilizer muscles in an attempt to reinforce the head-neck segment with the intention of attenuating the forces being placed against the head.

Due to trends in the demographics of those who report the highest rates of concussions in sports, individuals are able to theorize that weaker and lesser neck musculature may be the cause for higher concussion rates among younger athletes, female athletes, untrained individuals and more (McCroly et al., 2012). Additional results from Tierney et al. (2005) identify that female athletes have greater head-neck segment acceleration than males when their skulls are exposed to the same impact load. It is further explained that this discrepancy is due to women having less head mass, head girth and stiffness, or strength, in the neck than males (Tierney et al., 2005). Specifically it was discovered in a study performed by Tierney et al. (2005) that female athletes had 44% greater head acceleration than male athletes. Correlations between weaker neck development and musculature among children and females as compared to that of an average active male and the rates of concussions being less for the latter have led some to postulate that stronger neck musculature is beneficial to the minimizing of concussions in sports.

Many theories regarding the role of neck strength on minimizing concussions is often a result of inductive conclusions from results of studies like that of Tierney et al. (2005) which recognized differences in head acceleration based on gender and age. It was speculated that lower levels of neck strength, neck girth and head mass were causes of greater head-neck segment acceleration after impact in physically active women (Tierney et al., 2005).

### **Summary**

Biomechanical, pathophysiological and impact kinematics of sport related concussions are all factors that must be understood in order to further examine ways in which the incidence of concussion occurs and in turn ways it can be reduced. Additionally understanding the effects, both short and long term, and symptoms of sport related concussions assists sport practitioners, athletics trainers, and coaches alike to place an emphasis on the need for research to construct new safety strategies in order to provide a safer playing environment. Just like the lack of universal testing, diagnosing, recording and treatment of sport related concussions, preventative techniques to reduce the incidence of concussions in sport are no different. Currently research by Benson et al. (2013) has indicated several risk reduction strategies including equipment enhancement, rule changes as well as identifying weakened neck musculature as a possible factor. With the possibility of physiological factors associated with neck size, strength and muscle activation, new attention has been placed on the role of the muscles surrounding and stabilizing the head.

## **Chapter 4**

### **DISCUSSION**

Researchers have spent years determining the impact variables most closely associated with the incidence of concussions in football players. There is evidence in the critical mass that suggests strength training may mediate concussions if the severity of the below factors is reduced upon impact. Based on the results of Rowson et al. (2011), Viano and Casson (2007), and Eckner et al. (2014) acceleration of the head, force of the impact, neck strength, neck size, and neck stiffness or impact awareness are all factors that contribute to whether or not an athlete will become concussed. The sections below explain in further detail the elements of head acceleration, concussion injury threshold, cervical anatomy and movements, as well as neck stiffness and muscle activation. A final section on recommendations for future research is also presented.

#### **Head Acceleration**

Impacts between players in the game of football often come from many different angles and locations and can cause the head to accelerate in linear and lateral directions as well as rotational paths or a combination of the three (Benson et al., 2013). Raschke describes linear acceleration as the alteration in head velocity and the length of time of the impact (2011). In a study by Pellman and others it was discovered that linear acceleration was the highest correlated variable in receiving a concussion (2003). Other factors associated with affecting the linear acceleration include the level of play, position of play as well as the location of impact (Crisco et al., 2010).

Identifying linear acceleration as a main component in risk of concussion in football helps sport practitioners, such as strength and conditioning specialists, places an emphasis on

ways to improve an athlete's ability to react to an impact in a way that minimizes acceleration. As stated by Hildebrandt et al. (2013) muscle strength in the neck may jeopardize the athlete's ability to generate enough force to counter the concussive force impact that causes the brain to displace within the skull. The goal of the athlete and sport practitioner is to increase the neck circumference through muscle hypertrophy or increasing the strength and ability to more rapidly stiffen the neck. Angular acceleration of the head is often accompanied by linear and rotated acceleration after impact (Schmidt et al., 2014). Strengthening the neck in rotated and angled postures is more difficult and use of conventional machines such as the 4-way neck machine may not be as effective as alternative approaches. Mansell et al. (2005) discovered that after an 8-week isotonic strength training program muscle strength increased however no reduction in head-neck segment acceleration upon impact was seen. Isotonic exercises such as the 4-way neck machine may also not be effective due to its inability to improve muscle activation upon impact. Rather these exercises focus on improving strength in fixed positions while applying resistance to a load rather than a load abruptly being applied to the head such as an impact in football. These impacts also bring abrupt angular and rotational changes which must be strengthened using different techniques.

Manual resistance must be used in order to work the neck in different angles and rotations. Isometric contractions can provide constant muscle activation against resistance in these angular and rotated postures. Coaches and sport practitioners have to become creative in producing a contraction that is safe and conducive for loading the surrounding cervical muscles. Isotonic movements are no different when attempting to target angled and rotated postures. Neck harnesses provide the best opportunity for loading resistance onto the head and neck through angled and rotated postures. No evidence shows what's more conducive for strengthen the

cervical muscle to attenuate a football impact but isometric resistance can be held for time or isotonic strengthening can be performed for a specific number of sets and repetitions.

Collegiate and professional football players have a greater ability to be subjected to proper strength training programs that can aim at increasing muscle strength and size around the cervical area. Isotonic strength training is the most conventional method of strength training in use amongst sport practitioners however other methods can be utilized to help find an answer to reducing head-neck segment acceleration. Overall concussion incidences are most often affected by both linear and rotational accelerations of the head often caused by the dynamic play within the game of football. It is necessary to analyze the role of neck strength and neck stiffness and their ability to attenuate head acceleration after impact.

### **Concussion Injury Threshold**

A number of researchers including Broglio et al. (2010) and Brolinson et al. (2006) have attempted to examine if there is a force threshold that is optimal for individuals to receive a concussion. Due to studies often researching different demographics as well as the varying magnitudes and locations of impacts that result in concussions it has become difficult to designate a clear threshold for concussive impacts that can be applied to collegiate football players. A number of studies have sought out to identify a threshold for concussion injury. Broglio et al. (2010) reported on the results of a number of studies including the works of Pellman et al. (2006). It was stated that linear acceleration had the greatest relationship with concussion injury and an average threshold of 98g of impact force was recorded significant concussive injuries in professional football (Broglio et al., 2010). For sport practitioners this information assists in prioritizing which movements to place an emphasis on while strength training. Brolinson et al. (2006) specifically analyzed the force impact threshold of collegiate

football players and concluded that on 2.5% of impacts resulting in a concussion were above 75g. Similarly Broglio et al. (2010) reported on additional Pellman findings that stated an impact force as low as 70-75g was necessary for causing a concussive injury (2010). Translating forces capable of causing concussion into possible neck strength thresholds for linear movements could be helpful if sport practitioners aspired to discover the optimal neck size and strength associated with attenuating this level of impact.

Rotational and angular kinematics are associated with a concussions. Rowson et al. (2012) added a report on findings that included measurements of rotational kinematics associated with head impact accelerations in football players fitted with accelerometers. These findings concluded that the average sub-concussive impact received is four times less than the a rotational acceleration found in the average concussive impact which quadrupled to a rotational velocity indicating a need for the athlete to be able to withstand greater impact to avoid injury (Rowson et al., 2010). Equivalent to linear head acceleration, rotational acceleration must also be diminished in order to reduce the risk of movement of the brain within the skull. Understanding these thresholds again can be applied to strength training goals such as correlating an isotonic rotational strength that may dissipate these extreme forces.

Studies like examining forces and resulting brain trauma help to identify a threshold range rather than a specific figure in regards to the forces the head is experiencing upon impact. Understanding impact forces and identifying thresholds has led more to the development of new equipment, safer playing surfaces as well as creating a tool to better record impacts to the head that may have resulted in a concussion (Broglio et al., 2010). Additionally association between inter athlete variability with respect to their thresholds may lead to determining the role of neck musculature variables in the incidence of concussion in football players. Regardless past studies

have yet to research any relationship between force impact threshold, incidence of concussion and an optimal amount of neck size and strength to help dissipate impending forces on a football player. It can be assumed the force thresholds, or the force needed to accelerate the head enough to cause concussive symptoms, are different for those that have varying risk factors such as number of prior concussions, sex, age, sport, muscle fatigue, and playing position. In theory greater muscle strength, when anticipating the contact, may allow an athlete to endure a larger force impact. This conclusion can be drawn from studies described in above literature that show female and youth athletes being more susceptible to concussions from lower forced impacts. Future studies need to directly examine how neck strength and size correlates to head linear and rotational acceleration. Additional researchers must determine if relationships exists between maximal neck strength and minimizing the acceleration of the threshold ranges discovered to cause concussion.

### **Cervical Anatomy and Movement**

Researchers such as Eckner et al. (2014), Hildenbrand et al. (2013), Mansell et al. (2005), Mihalik et al. (2011) and Rowson et al. (2012) have begun to analyze the role of the cervical musculature surrounding the head and neck and its function in absorbing concussive impacts. A combination of vertebrae, muscles, nerves and blood vessels all unite to surround the neck and support the mass and movement of the skull. Movement includes the flexion, extension, protrusion, retraction, tilt, nod and rotation of the head all in the sagittal plane with the exception of rotation occurring in the transverse plane (Raschke, 2011). Understanding these movements of the head and neck is necessary for identifying areas of weakness during force application through isotonic and isometric strength training movements and more importantly throughout direct or indirect impacts to the head or body that cause head acceleration. In order to attenuate

concussive impacts throughout a football game or practice through the utilization of improved muscle strength, size and activation of the neck, we must develop strengthening programs that target the specific muscle most closely associated with the mitigation of head acceleration.

Below identifies the vast number of muscles and vertebrae utilized in the head-neck segment and provides insight into specific muscles that are utilized during strength training techniques.

Seven cervical vertebrae align to form the section of the spine that most closely supports the head. Two cervical vertebrae, the C1 and C2 also known as the atlas and axis vertebrae play an important role in supporting the weight of skull as well as the flexion of the head (Raschke, 2011). Specifically the atlas or C1 vertebrae conjoins with the occipital bone in order to create the atlanto-occipital joint while the axis or C2 vertebrae unites with the atlas to form the atlanto-axial joint which allows for the head to rotate in the transverse plane (Raschke, 2011). A report by Black identifies the main muscles necessary for flexion, extension and rotations of the head-neck segment as the sternocleidomastoid, rectus capitis anterior, longus capitus, and the longus colli (superior, inferior, and vertical) which all help to produce cervical flexion bilaterally while the rectus capitis posterior (major and minor), semispinalis capitis and splenius muscles generate cervical extension bilaterally (2007). Furthermore Raschke writes that the lateral flexion of the head is produced by the rectus capitis lateralis, oblique capitis superior, sternocleidomastoid and the splenius muscles and finally rotation occurs with the use of the sternocleidomastoid, rectus capitis posterior (major), semispinalis capitis (contralaterally), obliquus capitis inferior and again the use of the splenius muscles (2011).

Other supplementary muscles that are often considered to help support these movements as well as the dissipation of impact to the head include the trapezius muscles, multifundus and levator scapulae. Understanding the range of motion of the head-neck segment as well as the

anatomy involved in its movement allows one to effectively study the role of these factors during force application to the head and neck whether it be a concussive impact or a simple strengthening movement. The sternocleidomastoid and upper trapezius have been identified as the most necessary dynamic stabilizers located within the head-neck segment and likely assist in the attenuation of concussive impacts to the head (Black, 2007).

As discussed prior, isotonic resistance movements have become popular especially with utilizing a 4-way neck machine which allows for a resisted lateral flexion (left and right) and extension (front and backward) of the neck. Again the 4-way neck places an emphasis on strengthening fixed linear movements of the head-neck segment and has not been correlated to improving muscle activation upon impact especially with sporadic impacts that case rotational and angular components of acceleration in addition to linear. Regardless of the lack of supporting evidence of the use of this machine, the movements utilize the levator scapulae, longissimus and semispinals (capitis and cervicis), trapezius, sternocleidomastoid, and multifundus in order to allow flexion and extension of the neck while using the 4-way neck machine. Other techniques and devises can also be utilized to target the same areas such as a neck harness loaded with resistance, banded resistance or resistance as simple as a partner using their hand to apply force while the subject contracts the above muscles. When loading resistance to the head and neck it is generally recommended by strength professionals to load resistance above ear level for optimal force application.

Additional movements employed to strengthen the surrounding cervical muscles, like the shrug, use shoulder elevation with resistance to target trapezius muscles and is often administered in strength programs with unknown intention of strengthening supporting neck musculature. Shrugs can be altered to apply specific contraction to either the upper or lower

trapezius muscles. Similarly retraction movements of the scapular muscles are endless and also provide an overall improved cervical structure surrounding the head and neck. Variations of shrugs can include using resistance such as plate loaded barbell resistance, dumbbell resistance, machine/cable resistance, banded resistance and more all while being able to vary grips which target different muscle regions. Scapular shrugs for example target the upper back and more specifically activate the posterior deltoids, rhomboids and latissimus dorsi muscles through many pulling/rowing retraction movements. Cross and Serenelli add that the larger muscle groups such as the trapezius muscles and scapulae muscles are best trained by isotonic resistance training methods (2003). Adding to stabilization of the upper back muscles, Cross and Serenelli recommended the use of exercises referred to as I, T Y's in a prone position. This elevation and contraction of the rhomboids, trapezius and posterior deltoids assists in improving strength and stability critical to helping attenuate impacts to the head and body (Cross & Serenelli, 2003). As with most strength training exercises grips, resistance and techniques used can all be manipulated.

Strengthening the flexors and extensors within the cervical anatomy can also be executed by simple bodyweight exercises with the head that involve supinated and pronated head flexion and extensions along with neck rotations that develop and strengthen surrounding musculature through the maximum range of motion. These rotations often utilize simple head weight or manual resistance to provide activation of the head-neck segment muscle groups. Cross and Serenelli (2003) reported on the importance of the strength and stability of the cervical spine and its ability to attenuate concussive impacts to the head if properly trained. They added a number of resistance exercises that can train the surrounding muscles of the neck and spine both through isotonic and isometric loading. Cross and Serenelli (2003) state that manual resistance can be

more beneficial due to the alteration of resistance throughout the range of motion in training the neck muscles. This variation can help to strengthen weak points within the flexion, extension and rotation of the neck through varied range of motions. Recent studies have begun to indicate that impact awareness can possibly be the best resister of concussive forces due to the neck muscles stiffening prior to impact thus resulting in better absorption and attenuation of an impact to the head (Raschke, 2012).

### **Neck Stiffness and Impact Anticipation**

The head and neck are two separate segments that operate collectively to both generate and prevent movement of the skull. Neck stiffness refers to the head-neck segments ability to decrease and prevent movement of the skull through the tensing or activating of the anatomical features within and surrounding the neck (Raschke, 2011). This stiffness also referred to as preparedness thus decreases the movement of the brain within the skull and ultimately assists in the dissipation of an impact. In a study by Viano, Casson, and Pellman (2007) it was discovered that with the impact force being equal, concussion injury was not observed when the head and neck were fixed or stiff, however when the head was able to deviate from a fixed position, the same force led to a concussion injury.

Viano, Casson, and Pellman (2007) further explained that acceleration of the head during impact is greatly influenced by neck stiffness. Schmidt et al adds that by stiffening the neck and surrounding muscles, an individual is believed to increase the effective mass of the head by linking the head and thorax to create a more firm resistance reducing head acceleration (2014). A study performed by Eckner et al. (2014) also reviews the role of neck strength and activation of the neck muscles prior to impact as a possible means of attenuating the force of impact to the head and thus decreasing acceleration of the head and the brain within the skull. In a study that

looked at a wide range of demographics and age groups using a loading apparatus to apply impulsive forces to the athletes' heads in both the transverse and sagittal planes it was discovered that bracing for impact can in fact decrease the kinematic response of the head when being struck (Eckner et al., 2014). Schmidt et al report similar thoughts that early onset muscle activation may play a significant part in minimizing the severity of an impending impact to the head (2014). This study and the most recent study on this subject by Eckner et al. (2014) supported the postulation that both neck strength and anticipatory muscle activation are correlated with an attenuation of a concussive impact and the onslaught of concussion symptoms.

Disparity in neck strength and impact force dissipation between different demographics such as sport participants versus non sport participants has led to suggest that simply the participation in athletics can help strengthen and improve cervical muscle strength and activation. Hildenbrand and Vasavada (2013) support this idea by reporting findings that the collegiate athletic population in their study was had stronger cervical flexion and lateral flexion strength as compared to a general adult population. In addition it was stated that high contact sport athletes such as wrestlers had stronger neck strength than a control group as well (Hildenbrand & Vasavada, 2013). As a collegiate football player the tensing of the cervical musculature during anticipated collisions is necessary in order to better mitigate the intensity of an impact to the head (Eckner et al., 2014). Repetition of these movements throughout drills, practice and competition may be beneficial in both improve neck muscle strength and muscle activation as well as head-neck segment stiffness. If more research can prove that neck stiffness and impact anticipation is the main component to dissipating the force of a concussive blow to the head by minimizing the linear, angular and rotational acceleration of the head, the next task

will be discovering how sport practitioners can improve this reflex within their athletes using more controlled techniques such as strength training movements.

### **Recommendations**

After reviewing a number of studies it is shown that distinct factors affect the incidence of concussion among football participants at the collegiate level. Data has shown that not only are concussive impacts associated with an array of linear, angular and rotational accelerations but also neck stiffness or preparedness (Hildenbrand & Vasavada, 2013). Reductions in head linear, angular and rotational accelerations have been proven to minimize the risk of concussion in athletes. Furthermore it has been found that greater neck size and strength can help to attenuate the force of an impact to the head by effectively activating the muscles surrounding the neck to create a firm resistance against the impact (Eckner et al., 2014). It is clear that cervical strength training programs are able to increase neck size, isometric strength and isotonic strength. In spite of these findings a direct correlation between strengthening of the cervical musculature and a reduction in concussions in collegiate football players is still difficult to uncover. Many factors such as prior concussion history, failure to report or diagnose concussion, player fatigue and most importantly awareness of an impending impact hinder the testing of direct relationships between improvement in muscle strength and the reduction of concussions in football.

Plyometric training has been proven to help improve other muscle groups muscle activation. This same theory could be applied to the cervical neck musculature in an attempt to improve the muscle contraction as an impact ensues. A further look must be made at how muscle activation of the cervical muscles can be improved. Currently data only implies that isometric and isotonic neck strength can be improved through resistance movements. Additionally these strength gains have not helped to improve muscle activation (Eckner et al., 2014). These strength

gains are often difficult to connect to reduce incidence of concussion in football. Future research must be done to identify the role of muscle activation and neck stiffening upon impact. Eckner et al. (2014) has proven that quicker cervical muscle activation does improve the dissipation of an impact to the head however this study does not solve the problem of how to improve this activation. One can only theorize that plyometric training may improve this activation however creating resistance workouts to do so could be difficult.

### **Conclusions**

Discovering a preemptive strategy to lessen the incidence of concussion in sport is a top priority of sport practitioners and strength training personal alike. Head acceleration resulting from an impact has been identified as the main cause of producing the onslaught of pathophysiological changes within the brain after contact with the skull. Neck musculature has been identified as a possible factor that can be manipulated or improved in a way to help attenuate some of the impact force often experienced in an impact to the head in a game of football. Thus far no studies have substantiated claims that strength training of the cervical neck musculature directly correlates to the minimizing of concussions rated in collegiate football however it has been established that stronger necks and neck stiffness can help attenuate the rate of head acceleration due to impact. Study of these factors may prove valuable in helping reduce concussions in football, thus making the game safer.

## References

- Benson, B. W., McIntosh, A. S., Maddocks, D., Herring, S. A., Raftery, M. & Dvorak, J. (2013). What are the most effective risk-reduction strategies in sport concussion? *British Journal of Sports Medicine*, 47. 321-326.
- Broglio, Steven P., Schnebel, Brock., Sosnoff, Jacob J., Shin, Sunghoon., Feng, Xingdong., He, Xuming., & Zimmerman, Jerrad. (2010). Biomechanical properties of concussions in high school football. *Medicine & Science in Sports & Exercise*, 2064-2070.
- Crisco, J.J., Fiore, R., Beckwith, J.G., Chu, J.J., Brolinson, G., Duma, S., McAllister, T.W., Duhaime, A.C., & Greenwald, R.M. (2010). Frequency and location of head impact exposures in individual collegiate football players. *Journal of Athletic Training*. 45(6). 549-559.
- Cross, K.M., & Serenelli, C. (2003). Training and equipment to prevent athletic head and neck injuries. *Clinics in Sports Medicine*. 22. 639-667.
- Eckner, J. T., Youkeun K. O., Joshi, M. S., Richardson, J. K., & Ashton –Miller, J. A. (2014). Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head impulsive loads. *The American Journal of Sports Medicine*, 42(3). 566-576.
- Guskiewicz, K. M. & Mihalik, J. P. (2011). Biomechanics of sport concussion: Quest for the elusive injury threshold. *Exercise Sport Science Review*, 39(1), 4-11.
- Harmon, K.G., Drezner, J.A., Gammons, M., Guskiewicz, K.M., Halstead, M., Herring, S.A., Kutcher, J.S., Pana, A., Putukian, M., & Roberts, W.O. (2013). American medical society for sport medicine position statement: concussion in sport. *British Journal of Sports Medicine*, 47, 15-26.

- Hildenbrand, K. J. & Vasavada, A. N. (2013). Collegiate and high school athlete neck strength in neutral and rotated postures. *Journal of Strength and Conditioning Research*, 27(11), 3173-3182.
- Herring, S.A., Bergfeld, J.A., Boland, A., Boyajian-Oneil, L.A. Cantu, R.C., Hershman, E., and et al. (2011). Concussion (mild traumatic brain injury) and the team physician: A consensus statement. *Medicine and Science in Sports and Exercise*, 37, 2012-2016.
- Levy, M.L., Oygur, B.M., Berry, C., Aryan, H.E., & Apuzzo, M.L. (2004). Analysis and evolution of head injury in football. *Neurosurgery*, 55(3), 649-655.
- Lovell, M.R. (2009). The management of sports-related concussion: Current status and future trends. *Clinical Sports Medicine*, 95-111.
- Makdissi, M., Darby, D., Maruff, P., Ugoni, A., Brukner, P., & McCrory, P.R. (2010). Natural history of concussion in sport: Markers severity and implications for management, *The American Journal of Sports Medicine*, 38(2), 464-471.
- Mansell, J., Tierney, R. T., Sitler, M. R., Swanik, K. A., & Stearne. (2005). Resistance training and head-neck segment dynamic stabilization in male and female collegiate soccer players. *Journal of Athletic Training*, 40(4), 310-319.
- Marar, M., McIlvain, N.M. Fields, S.K. & Comstock, R.D. (2012). Epidemiology of concussions among United States high school athletes in 20 sports. *American Journal of Sports Medicine*, 40(4), 747-755.
- Marshall, C. M. (2012). Sports-related concussion: A narrative review of the literature. *The Journal of the Canadian Chiropractic Association*, 56(4). 299-310.

- Mihalik, J. P., Guskiewicz, K. M., Marshall, S. W., Greenwald, R. M., Blackburn, J., & Cantu, R. C. (2011). Does cervical muscle strength in youth ice hockey players affect head impact biomechanics? *Clinical Journal Of Sport Medicine*, 21(5), 416-421.
- Minnesota Epilepsy Group, P.A., <http://mnepilepsy.org/patient-information/concussion-short-and-long-term-impact/>
- McCrory, P., Meeuwisse, W. H., Aubry, M., et al. (2013). Consensus statement on concussion in sport: The 4th international conference on concussion in sport held in Zurich, November 2012. *British Journal of Sports Medicine*, 47, 250-258.
- Pellman, E.J., & Viano, D.C. (2006). Concussion in football: Summary of the research conducted by the national football league's committee on mild traumatic brain injury. *Neurosurgery Focus*, 21(4)
- Raschke, Cameron L. (2011). The role of isometric neck strength in predicting concussions sustained by high school football players. Unpublished master's thesis, University of Texas at El Paso, El Paso, TX.
- Rowson, S., Duma, S.M., Beckwith, J.G., Chu, J.J., Greenwald, R.M., Crisco, J.J., Brolinson, P.G., Duhaime, A.C., McAllister, T.W. & Maerlender, A.C. (2011). Rotational head kinematics in football impacts: An injury risk function for concussion. *Annals of Biomedical Engineering*. 40(1) 1-13. Doi: 10.1007/s10439-011-0392-4.
- Ryan, T. T. (2005). Gender differences in head–neck segment dynamic stabilization during head acceleration. *Medicine & Science in Sports & Exercise*, 37(2), 272-279.
- Schmidt, J.D., Guskiewicz, K.M., Blackburn, T., Mihalik, J.P. Siegmund, G.P. & Marshall, S.W. (2014). The influence of cervical muscle characteristics on head impact biomechanics in football. *The American Journal of Sports Science*. x(x). 1-11.

Signoretti, S., Lazzarion, G., Tavazzi., & Vagnozzi, R. (2011). The pathophysiology of a concussion. *The American Academy of Physical Medicine and Rehabilitation*. (3), 359-368.

Tierney, R. T., Sitler, M. R., Swanik, B. C., Swanik, K. A., Higgins, M., & Torg, J. (2005). Gender differences in head-neck segment dynamic stabilization during head acceleration. *Medicine & Science in Sports & Exercise*, 37(2), 272-279.

Viano, D.C., Casson, I.R., & Pellman, E.J. (2007). Concussions in professional football: Biomechanics of the struck player – part 14. *Neurosurgery*. 61(2). 313-328.

## APPENDIX A

## Findings on Neck Strength

Benson, B. W., McIntosh, A. S., Maddocks, D., Herring, S. A., Raferty, M. & Dvorak, J. (2013).

What are the most effective risk-reduction strategies in sport concussion? *British Journal of Sports Medicine*, 47. 321-326.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effectiveness of protective equipment, rule changes, neck strength and legislation on reducing the risk of concussion in sport.	11 electronic database searches, grey literature, and bibliographies were searched for relevant literature on the subject	Inclusion/exclusion criteria were used to select articles for the study. Citations for specific words linked to the study were quantified per database and later assessed.	No evidence was provided to suggest an association between neck strength increases and concussion risk reduction. A multifactorial approach is needed for concussion prevention.

Broglio, Steven P., Schnebel, Brock., Sosnoff, Jacob J., Shin, Sunghoon., Feng, Xingdong., He, Xuming., & Zimmerman, Jerrad. (2010). Biomechanical properties of concussions in high school football. *Medicine & Science in Sports & Exercise*, 2064-2070.

Problem Statement	Subjects/Instruments	Procedures	Findings
To identify the main biomechanical characteristics associated with concussions in sports.	78 high school athletes with an average age of 16.7  Head Impact Telemetry System	HIT System used to record number of impacts, magnitude of rotational acceleration, linear acceleration and impact location  Regression analysis conducted to discover trends	54,247 impacts were recorded with 13 concussion episodes captured. Data indicated that rotational acceleration (>5582.3 rads), linear acceleration (>96.1g) and impact location yielded the highest

			predictive value of concussion.
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Eckner, J. T., Youkeun K. O., Joshi, M. S., Richardson, J. K., & Ashton –Miller, J. A. (2014).

Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head impulsive loads. *The American Journal of Sports Medicine*, 42(3). 566-576.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads.	46 male and female contact sport athletes aged 8-30.  Impulsive loading apparatus provides isometric force application in multiple head postures. Head Kinematics were measured using an Optotrak motion capture system. Statistical analysis' were performed using SAS version 9.3	Isometric neck strength was measured in each anatomic plane while a loading apparatus applied impulsive force to the athletes' head in different positions then responses were measured.	Greater neck strength and anticipatory cervical muscle activation can reduce the magnitude of the heads kinematic response.

Hildenbrand, K. J. & Vasavada, A. N. (2013). Collegiate and high school athlete neck strength in neutral and rotated postures. *Journal of Strength and Conditioning Research*, 27(11), 3173-3182.

Problem Statement	Subjects/ Instruments	Procedures	Findings
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Examine the differences in isometric neck strength between college and high school athletes and between male and female athletes in neutral and rotated postures.	149 total subjects, 77 men, 72 women, 90 college level and 59 high school level.	Flexion, extension and lateral flexion neck strength were measured using a multi-cervical unit following the Melbourne Protocol	Neck strength was greatest extension. Females had 56-61% the neck strength as males. High school athletes had 65-75% the strength of college athletes.
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Mansell, Jamie., Tierney, Ryan T., Sitler, Michael R., Swanik, Kathleen A., & Stearne, David. (2005). Resistance training in head-neck segment dynamic stabilization in male and female collegiate soccer players. *National Athletic Trainers' Association, Inc*, 40(4) 310-319.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effect of an 8-week cervical resistance training program on head neck segment dynamic stabilization in female collegiate soccer players.	36 NCAA division I collegiate soccer players, 17 men and 19 women with an average age of 19.  Anthropometric assessments, External force applicators, PEAK Motus Motion analysis system, Noraxon Telemyo system, Head-neck segment strength assessments.	Pretest/posttest resistance training group underwent a training program and was compared against a control group that underwent no training.  Kinematic, head acceleration and displacement, electromyography, neck stiffness and neck strength measurements were taken.	No kinematic, electrographic, or stiffness training effects were seen. Neck strength and girth increased for both male and female participants in the training group.

Mihalik, J. P., Guskiewicz, K. M., Marshall, S. W., Greenwald, R. M., Blackburn, J., & Cantu, R. C. (2011). Does cervical muscle strength in youth ice hockey players affect head impact biomechanics? *Clinical Journal Of Sport Medicine*, 21(5), 416-421.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effect of cervical muscle strength on head impact biomechanics.	37 volunteer ice hockey players age 15 on average.  Subjects equipped with accelerometer-instrumented helmets.	Measure isometric cervical strength in different postures and correlate the measurements to impact acceleration readings.	.The hypothesis that players with higher static neck strength would experience lower resultant head accelerations was not supported.

Raschke, Cameron L. (2011). The role of isometric neck strength in predicting concussions sustained by high school football players. Unpublished master's thesis, University of Texas at El Paso, El Paso, TX.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effect of differences in isometric neck strength among concussed vs. non concussed football players on the incidence of concussion.	32 high school football players where 16 had no concussion history and 16 had prior concussion history.  Biodex machine with head harness used to measure neck strength. Questionnaires to determine prior head trauma injury.	Strengths in different postures were recorded and compared to prior concussion history information using MANOVA statistical analysis.	There was no significant differences in neck strength with a football-related concussion history and those without.

Rowson, S., Duma, S.M., Beckwith, J.G., Chu, J.J., Greenwald, R.M., Crisco, J.J., Brolinson, P.G., Duhaime, A.C., McAllister, T.W. & Maerlender, A.C. (2011). Rotational head

kinematics in football impacts: An injury risk function for concussion. *Annals of Biomedical Engineering*. 40(1) 1-13. Doi: 10.1007/s10439-011-0392-4.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effect of rotational head kinematics of the head associated with concussive impacts on the ability to predict brain injury.	335 collegiate football players between 2007 and 2009 were instrumented with accelerometer arrays that measured head acceleration for every impact. The HIT System and a custom 6 degree of freedom measurement were used to collect the data.	Data was measured using the HIT system and 6DOF system, Data was then recorded and analyzed using regression analysis.	300,977 impacts were recorded with 57 concussions. An injury risk curve was developed and a nominal injury value of 6383 rad/s associated with 28.3 rad/s represents 50% risk of concussion.

Signoretto, S., Lazzarion, G., Tavazzi., & Vagnozzi, R. (2011). The pathophysiology of a concussion. *The American Academy of Physical Medicine and Rehabilitation*. (3), 359-368.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effect of stronger and larger necks in high school and football players on reduced odds of sustaining higher magnitude head impacts throughout the season.	49 football players (34 high school, 15 collegiate).  HUMAC NORM testing and rehabilitation system was used to measure isometric strength, muscle size, and response to cervical perturbation.  HIT system was used to measure head impacts for each player.	Preseason cervical testing protocols measuring isometric strength, muscle size, and response to cervical perturbation were recorded and compared to HIT system data.	Greater cervical stiffness and less angular displacement after perturbation reduced the odds of sustaining higher magnitude head impacts. Findings did not prove that stronger and larger necks mitigate head impact severity.

Tierney, R. T., Sitler, M. R., Swanik, B. C., Swanik, K. A., Higgins, M., & Torg, J. (2005).

Gender differences in head-neck segment dynamic stabilization during head acceleration.

Medicine & Science in Sports & Exercise, 37(2), 272-279.

Problem Statement	Subjects/ Instruments	Procedures	Findings
The effect of gender differences on head-neck segment stabilization during head acceleration	40 physically active volunteers were used in this study (20 females and 20 males).  External force applicator, PEAK Motus Motion Analysis system, Noraxon Telemetry System, Microfet hand-held dynamometer.	Trials using an external force applicator were run without participants knowledge of force application in order to simulate sport situations. Trials had subjects prepared and un prepared for impacts and results were recorded. Descriptive and inferential statistics were run.	Females experienced greater head-neck segment peak angular acceleration, and head displacement. Females also exhibited less isometric strength, neck girth, and head mass resulting in lower levels of head-neck segment stiffness.

Viano, D.C., Casson, I.R., & Pellman, E.J. (2007). Concussions in professional football:

Biomechanics of the struck player – part 14. *Neurosurgery*. 61(2). 313-328.

Problem Statement	Subjects/ Instruments	Procedures	Findings
To determine the impact biomechanics of the struck player in professional football.	25 laboratory reconstruction of NFL game impacts were used to measure a number of biomechanical variables	25 helmet impacts were reconstructed using Hybrid III dummies. Head impact velocity, direction and helmet kinematics-matched to game video.	Peak accelerations of 94g and 6432 r/s and velocity changes of 7.2 m/s and 34.8 r/s. Neck strength may influence head velocity and head injury.