Assessment, Feedback and Head Accelerations in Youth American Football

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy
in the Graduate School of The Ohio State University

By

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2016

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Abstract

Reports estimate 1.6 to 3.8 million cases of concussion occur in sports and recreation each year in the US, with sports related concussion(SRC) affecting more than 5% of high school and collegiate football players. The American Academy of Pediatrics issued a 2015 position statement on tackling in football that recommended "officials and coaches must enforce the rules of proper tackling, including zero tolerance for illegal, head-first hits." USAFootball, a large youth football organization, has recommended a head up, vertical tackling style in an effort to improve tackling form and reduce subsequent injuries, yet no research has been performed to identify the effect of this method on head accelerations nor an effective method of teaching this method. Video feedback is a common motor learning technique used in many situations to alter movement patterns to prevent injuries and improve athletic performance. *The purpose of this research was to understand the effect of video feedback on movement performance and determine if the head up, vertical tackling style is effective in reducing head accelerations in youth football athletes.*

Aim 1 of this study established the inter-rater agreement of the Qualitative Youth Tackling Scale (QYTS) during video review of tackling in youth football players. Providing consistent feedback between raters is a critical aspect of motor learning. Aim

2 determined the effect of self-observation, expert and self plus expert feedback models in the performance of the six body position variables of interest in the instructed tackling skill. Establishing the effect of these models allows coaches and trainers to effectively provide feedback to their athletes. Aim 3 examined changes in head acceleration from baseline to after a training program in a head up, vertical tackling style. Understanding the effect of body position on head accelerations during tackling will help to design tackling forms that minimize injury risk in athletes.

The results of Aim 1 of this study indicates skilled raters are better able to identify the movement patterns included in the QYTS when compared to a validation measure as well have higher rates of inter-rater agreement than novice raters. Aim 2 results indicate that the model utilized did not impact the improvement for cervical angle or shoulder angle over verbal feedback alone. Step length and pelvic height responded positively to the self and expert model, improving performance more than the other feedback conditions though these results were not significant. There was no change in trunk angle during the training sessions. Aim 3 results indicated receiving training in a head up vertical tackling style reduced the number of impacts over 10gs experienced by the tacklers over a 1 day treatment session. Odds ratios of experiencing head acceleration over 10gs increased significantly for those with step lengths and pelvic height on impact over the recommended pattern. Taken together the results of this study indicate trained evaluators are capable of providing the feedback necessary to improve tackling performance, providing verbal feedback improved tackling performance, and training in proper tackling techniques can decrease the number of head accelerations experienced by participants.

Dedication

To Ellare and Frank,

You were the example for us all.

To Mom and Dad,

Thank you for all your love and support. You have both been there for me every day.

To Korrin,

One day my soul went, Oh, there you are. I have been looking for you.

Acknowledgments

I would like to acknowledge my committee for all of their work and support through this project. Your willingness and dedication made this project possible.

I would like to specifically thank Dr. Jimmy Onate for his mentorship and support through this journey. While learning to swim I managed to inhale my fair share of water, but I have learned to find my own way.

I would like to thank all those who have helped me through the program: Dr. Dustin Grooms, Dr. Louise Thoma, Meghan Miller, Mike McNally, Cambrie Starkel and Dan Clifton. I never could have done it without your help and support.

Thank you to my entire family. Your unending support has been the bedrock on which everything has been possible for me.

Vita

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Chapter 1: Aims, Limitations and Delimitations

A 2015 position statement by the American Academy of Pediatrics recommended "Officials and coaches must enforce the rules of proper tackling, including zero tolerance for illegal, head-first hits"[8]. In 2015, eight high school football athletes' deaths were directly related to head and spine injury[9]. Reports estimate 1.6 to 3.8 million cases of concussion occur in sports and recreation each year in the US, with sports related concussion rate estimates between 0.19 and 1.78 per 100,000 participants[10,11]. Despite continued efforts to reduce the occurrence of concussion, the incidence of these potentially devastating injuries continues to increase[12]. Head contact during blocking and tackling are the most prevalent mechanisms of injury or activity associated with concussion[13]. Video feedback is a common motor learning technique that has been used in many situations to alter movement patterns in hopes of preventing injuries and improving athletic performance[3–7]. The model utilized by the video feedback technique can have an effect on the information the learner receives from feedback[14,15], to date the effect of feedback model type in football tackling has not been described. USAFootball, a large youth football organization, has recommended a head up, vertical tackling style in an effort to improve tackling form and reduce subsequent injuries[16], yet no research has been performed to identify the effect of this method on head accelerations nor an effective mechanism for athletes to learn this method. *The purpose of this research was* *to understand the effect of video feedback models on movement performance and determine if the head up, vertical tackling style recommended by USAFootball is effective in reducing head accelerations in youth athletes.*

Aim 1

Statement of Problem

Providing verbal feedback to an athlete is critical to improving performance even when providing other modes of feedback. There is no structured mechanism to provide feedback on performance of a head up, vertical tackling style like the USAFootball Heads Up tackling mechanism. Development of this mechanism must be representative of the movement desired and capable of providing consistent feedback to the learner. This aim sought to determine the construct validity and agreement of the Qualitative Youth Tackling Scale (QYTS) during video review of tackling in youth football players.

Null Hypothesis

Both Certified Athletic Trainer's (ATC) and novice raters will be unable to correctly identify the successful performance of the desired movement pattern when performing a video review of a tackle.

Research Hypothesis

Evaluators will achieve a moderate level of agreement when evaluating the inter-rater agreement and validity of each of the performance variables from the QYTS.

The independent variables for this study were:

- Individuals performance of the 6 criteria from the QYTS:
    1. cervical extension past 45 degrees on contact
    2. trunk angle between 35 and 55 degrees on contact
    3. head placement across the front of the target
    4. pelvic height less than 75% of standing pelvic height during the last 0.25s prior to contact
    5. shoulder extension mean in the last 0.5s prior to contact
    6. step length over the last 250 cm on approach to the target

Dependent variables for this study were:

- Fliess' Kappa scores between all raters
- Cohen's Kappa scores, positive and negative agreement percentage between:
    - ATC
    - Novice
    - ATC and Novice
    - ATC and Motion capture
    - Novice and Motion capture
- Averaged banded Cohen's Kappa between all raters and 100% to 80% of validity measure

Aim 2

Statement of Problem

Feedback is one of the most direct methods of teaching a new movement skill. Feedback utilizing video of the performer has been utilized in many areas of skill development and sport. The model utilized during training may impact the effectiveness of the intervention. Research on the effect of model type during football tackling training has not been performed to date. The purpose of this research aim was to determine the effect of self-observation, expert and self plus expert feedback models in the performance the instructed tackling skill.

Null Hypothesis

There will be no statistically significant difference in performance in the treatment groups. There will be no difference in performance of cervical extension, trunk angle, head placement, pelvic height, shoulder extension and step length.

Research Hypothesis

Self plus expert model learners will better perform the instructed tackling form over the other studied feedback models

The independent variables for this aim were:

- Self as model feedback
- Expert as model feedback
- Self and expert as model feedback
- Verbal Feedback only

The dependent variables for this aim were performance of:

- Degrees cervical extension angle on contact
- Degrees trunk angle on contact
- Degrees averaged bilateral peak shoulder extension angle in 0.5 seconds prior to contact
- Percent of standing pelvic height
- Average percent pelvic height in 0.25 seconds prior to contact
- Average bilateral step length

Dichotomous variable

- Head placement across the front of the target

These variables were analyzed at baseline, after instruction in the desired form and at the end of training.

Aim 3

Statement of Problem

Sports related concussions affect a large number of athletes and are a vital concern for the medical community as a whole. Recommendations have been made to teach proper technique in order to reduce the head accelerations experienced while tackling, yet there is minimal evidence that the recommended techniques reduce the head accelerations experienced by football style tacklers. The purpose of this study was to determine the effectiveness of a head up, vertical tackling technique on the head accelerations experienced by the performer.

Null Hypothesis

There will be no difference in the number of head accelerations over 10gs experienced by players who are trained in a head up, vertical tackling style.

Research Hypothesis

Athletes who are trained in the instructed USAFootball Heads Up tackling form will experience a lower number of head accelerations over 10gs when compared to their baseline head accelerations.

The independent variables for this aim were:

Head accelerations experienced at Baseline and Post Training time points

The dependent variables for this aim were:

Number of head accelerations per participant over 10gs at each time point

Operational Definitions

- Certified Athletic Trainer (ATC): Person who has completed the education requirements and passed the certification exam specified by the Board of Certification, Inc. (BOC) to practice as an Athletic Trainer.
- Novice Rater: A person who does not have significant experience and training in utilizing visual estimation of movement in a healthcare setting.
- Motion Capture: The Vicon MX40 series 10 camera system utilized to track and analyze movement in three dimensions.

- Self-Feedback Group: The Self-Feedback Group received video and verbal feedback regarding their tackling performance using only the participant as a model in the video feedback. Verbal feedback was standardized based on errors.
- Expert Feedback Group: The Expert Feedback Group received video and verbal feedback regarding their tackling performance using only video of an expert as a model in the video feedback. Verbal feedback utilized the same standardized format as all other groups.
- Combination Feedback Group: The Combination Feedback Group received video and verbal feedback regarding their tackling performance using both the participant and an expert as model. Verbal feedback utilized the same standardized format as each of the other groups.
- Verbal only Group: The verbal only group did not receive any video feedback but received verbal feedback in the same standardized format as all other groups.
- Cervical Extension: Head segment position compared to the trunk segment in the X plane at contact. Measures zeroed by subtracting cervical extension measure from initial data calibration trial.
- Mean Trunk Inclination: The position of the trunk segment compared to the lab coordinate system in the X plane averaged over 0.25s prior to body contact.
- Mean Percent of Standing Pelvic Height: Distal height of the pelvis compared to the lab coordinate system segment in the Z plane averaged over 0.25s prior to contact.

- Mean Bilateral Peak Shoulder Extension: Highest data value reported by the motion capture system for shoulder extension, the shoulder segment compared to the trunk segment in the X plane, of each side over 0.50s prior to contact averaged between sides.
- Mean Step Length: The distance between foot strikes of the right and left side independently over last 250 cm of approach. Average of right and left side step length normalized to standing pelvis height.
- Head Placement: Identified as placement of the head on the near side of the target using video review of the trial.
- Linear Acceleration: Three piezoelectric accelerometers are set orthogonally within the xPatch system. The system records the linear accelerations reported from each of these independent accelerometers, transforms the data from accelerations at the side of the head to the center of gravity of the head and then calculates the magnitude of the vector. The linear accelerations are measured every 1/100th of a second while the device is on. When the measurement of linear acceleration crosses a user selected threshold the device records from 10ms prior to threshold to 90ms after threshold.
- Peak Linear Acceleration: The length of the combined three axis linear acceleration measurement in which the recorded vector length is longest during a 100ms data window.

- Impact over 10g: An impact in which the average of peak linear acceleration measures from xPatch devices placed on the left and right side of the subject is over 10g’s.

Assumptions

- The motion capture cameras were accurately calibrated for all measurements.
- The accuracy of the xPatch system reliably measured the head acceleration values experienced by the participant and applied correctly to the participant.
- The time stamps between the video recorded by the feedback system and xPatch devices remained synchronized.

Limitations

- Feedback was limited to one session under controlled conditions in a research laboratory.
- Participants were limited to 9-13 year olds.
- Participants had varying degrees of football experience and come from multiple leagues.
- Participants were previously instructed by coaches from differing backgrounds, experience and education.
- The instructional technique was limited to the Heads Up Technique.
- No controls were established to track learning disability, measure visual acuity, track attention during training, and measure functional capacity.

Delimitations

- Feedback was provided utilizing a tablet based program that is freely available.
- Any subject who had a lower extremity injury or concussion history over the past 6 months was excluded.
- Data for variability in experience was collected and can be statistically controlled.
- The Heads Up tackling style is typically taught to athletes of this age. Older athletes are instructed in other tackling techniques by USAFootball.
- Athletes with learning disabilities, visual and attention issues participate in football; therefore their inclusion in this study ensures a naturalistic approach to the issues at hand.

Chapter 2: Literature Review

The following review of the literature will discuss the current knowledge base regarding tackling safety, tackling technique, cervical spine injuries and sports related concussion when tackling, motor learning techniques to alter tackling form and the effect of model type in video feedback on its effectiveness. Successful development of an intervention program requires consideration of the known information across all of these disciplines. While understanding the causative factors, the effects and treatment of concussion has been discussed at great length within the literature, prevention of sports related concussion in football is a developing field.

Tackling in Football

Tackling compared to other injuries

Injury is an unfortunate possibility while participating in youth athletics. The overall injury rate for athletes in grades four through eight is reported to be 8.4 to 17.8 per 1000 athlete exposures[17,18]. The most often occurring injuries were contusions, sprains and strains primarily of the wrist, knee and ankle/foot[17]. 3.4% to 7% of all injuries were considered neurologic or head/neck related[17,18]. The majority of concussions in 8-12 year old football athletes (45%) are caused by head to head contact with another player[19]. At the college level the highest incidence of concussion occurs through player contact while blocking (20.4%), followed by player contact while tackling (19.9%)[13]. Player contact while being blocked (11.9%) and while being tackled (14.4%) were slightly lower[13]. Head and neck injuries make up a small portion of the total injuries reported but may be considered one of the most concerning issues regarding injury in youth football.

Head injuries

In the time period from 1869 to 1905 American football saw 18 deaths and 159 serious injuries during practice and competition[20]. In 1939 the National College Athletic Association mandated the use of helmets, followed the next year by the National Football League. This action was enacted in an attempt to decrease cranial fracture experienced during participation[20]. The primary goal of the helmet was to decrease linear loading of the cranium, noting that helmets were not designed to stop rotational accelerations of the head[20]. Founded in 1969 the goal of the National Operating Committee on Standards for Athletic Equipment (NOCSAE) was to develop the first safety standards for football helmets. Following implementation of the NOCSAE standards, a 74% reported decrease in fatalities and a decrease in serious head injuries from 4.25 per 100,000 to 0.68 per 100,000 participants occurred[21].

Effect of type of participation on injury

Concussion plays a large role in time loss injuries within youth football. Concussion rates for youth football athletes per the Youth Football Surveillance Network accounted for 9.6% of all injuries in youth football in 2012 and 2013[22]. The injury rate at this level in game play was 2.38 to 6.16 per 1000 athlete exposures (AE) and 0.24 to 0.59 per 1000

AE in practice[19,22]. The median and 95th percentile linear acceleration and rotational acceleration for 9-12 year old athletes was significantly different between games and practices, with game accelerations being higher[23]. This trend does not carry forward into 12-14 year olds, who show no difference in accelerations experienced between practice and games[24]. These injuries can affect a large number of athletes when extrapolated over the number of participants.

The rate of concussion during practice may be related to the equipment worn during those events. The highest rate of concussion during college level practices was seen during full pad practices (0.66 per 1000 AE) followed by shells (0.33/1000 AE) and then helmets only (0.03 per 1000 AE)[25]. Though not discussed in this research, these levels of equipment typically align with the level of contact during the practice. Full pads are worn only during full contact practices, whereas in practices where contact is to be minimal, shells or helmets only are worn. This statement is supported by additional research indicating significantly higher numbers of impacts during games (24.1±19.1 per athlete per session) than contact practices (10.5 ±7.7 per athlete per session) and non-contact practices (2.4 ± 1.4 per athlete per session)[26]. These studies indicate minimizing full pad, full contact practices may reduce the impact load experienced by athletes.

League effects

Recent research may indicate the effectiveness of the Heads Up Football instruction in reducing head accelerations and injury rates in youth football athletes. Heads Up Football (HUF) league coaches receive hands on training regarding proper equipment fitting, didactic and participant demonstration of proper tackling technique and instruction in drills that reduce head contact[27]. Participants in HUF leagues experienced less head impacts during practice registering both 10 and 20g's when compared to non-HUF leagues[27]. The HUF leagues also saw a decrease in practice injury rates when compared to non-HUF leagues[28]. Utilization of HUF practice recommendations shows the ability to mitigate injury risk in youth athletes, though the effect of the tackling technique may not be the primary driver or may not translate to game performance.

Tackling Styles

Currently, there are two different tackling mechanisms recommended to minimize the head impacts while maintaining performance. The mechanism receiving the most publicity for youth programs at this time is the USAFootball Heads-Up framework. This framework contains recommendations for a specific tackling style as well as progressions to introduce the new tackling skill. USAFootball along with the National Football League (NFL) have created a training program emphasizing safety guidelines that also contains a tackling style that encourages a head up cervical posture and an erect torso to minimize head contact [16](**Figure 1**). This tackling mechanism involves maintaining an erect thoracic and lumbar spine, bent knees and low center of mass, while positioning the head across the front of body of the ball carrier and maintaining an extended cervical posture. In this tackling form, the neck is kept in an extended posture to protect the spinal column, yet is still put in a location that allows for contact from the opponent. A second tackling style has been recommended and publicized by the Seattle Seahawks coach Pete Carroll [29] and utilized by many professional and collegiate teams (**Figure 2)**.

This style is influenced by the tackling style used in rugby. Rugby participants do not wear helmets that provide the protection

Figure 1. An example of USAFootball Heads-up style

Figure 2. Example of Rugby Style Tackling. Copyright The Ohio State University Rugby Club.

of a football helmet and have developed mechanisms to limit head contact all together. The rugby style tackle emphasizes removal of the head from the line of movement during tackling[30]. Tacklers bring the trunk to a position near parallel to the ground, initiate contact with the superior aspect of the shoulder and arm, place the head on the posterior aspect of the pelvis and wrap the arms around the thighs and knees of the opponent when performing a shoulder tackle. The recommended attack point is much lower than typical techniques and may limit the ability of the player to maintain an extended cervical posture. This posture limits the ability of the cervical musculature to absorb impacts that may occur. The effect of either of these tackling styles on head accelerations and cervical angle has not been studied at this time.

Coaches and trainers often choose between teaching rugby based style or a heads up style based on various factors such as their past playing and coaching experiences or the perceived strength and coordination of the athlete, yet no research indicates a higher risk of injury due to performance failures from decreased strength or control. Research evaluating the incidence of concussion in youth rugby indicates ranges from 0.2 to 6.9 concussions per 1000 player hours in rugby union and 4.6 to 14.7 concussions per 1000 player hours for rugby league, with increased injury rates in higher levels of competition [31]. Younger rugby athletes tend to have lower cervical extension strength (12 years, 18kg± 3.1) than high school age rugby athletes (18 years, 34kg ±8.1) and elite senior athletes (24 years, 65kg ±2.45) [32,33]. Maintaining an extended cervical posture requires increased activation of the sternocleidomastoid along with the upper and lower trapezius muscles which may be beyond the strength, control and endurance capabilities of a youth athlete [34]. Increased isometric strength and anticipatory activation have been indicated to reduce the response to impulse loading [35] and researchers suggest this may be protective against concussion[36]. Other researchers propose that cervical stiffness may be the primary factor in decreasing the head impulse during contact[37]. The ability to control the core musculature has been related to athletic performance in football[38] and knee injury risk [39] among other injuries. A minimum level of core stability and control is theorized to be required to maintain a horizontal position when attempting a rugby roll style tackle [40]. Based on the rationale of inadequate core control in youth football players, USAFootball determined a heads up vertical style would be more appropriate for youth athletes. For athletes with higher core stability and neck strength as typically seen with maturation, adapted rugby roll style tackles may be more appropriate, but future research is needed to prove these clinical concepts. A vertical style places the athlete at a mechanical disadvantage when competing against a stronger and less contact adverse opponent. Despite these reports, the effect of strength and body movement control on maintaining a position during tackling is not known at this time.

Many commentators in the area of football injury have speculated that removing helmets from players may reduce the number and acceleration amplitude during head impacts. Instructed rugby style tackling involves maintaining the head toward the side of attack and making contact with the opponent at waist level. This style allows the head to not be pinned beneath the player as they are taken to the ground while completing an effective tackle. Injury rate ratios for youth and collegiate football players during competition are 1.86 and 1.57 per 1000 athlete exposures respectively[22]. Injury rates in rugby have been reported between 0.2 and 14.7 concussions per 1000 player hours for youth rugby union and rugby league play[31]. The concussion incidence for both sports is comparable despite rugby's lack of helmet use. This result may be due to the continued aggressive nature of both sports and not strictly related to the use of headgear. The head accelerations experienced during rugby tacking have been related to tackle distance in football[41]. Tackle distance is the space between players as they begin to move toward contact. In American football opposing player can have distances of over 20 yards to develop impact speed whereas tackling distance in rugby tends to be lower[41,42]. Despite these differences, utilizing a rugby style tackle along with the protection of the helmet may reduce the head acceleration burden on players.

Rugby style tackling as it has transitioned to use in American football has undergone form changes specific to each developer. The style of tackle utilized in the game of rugby is fairly standardized. The technical criteria for a rugby style tackling includes[43]:

1. Contacting the target in the center of gravity
2. Contacting the target with the shoulder
3. Body position square/aligned
4. Leg drive upon contact
5. Watching the target onto the shoulder
6. Centre of gravity forward of base of support

The primary focus of the tackle is to engage the player low, wrap the legs with the arms to stop their forward drive ability and keep the head on the near side of the target to reduce the risk of head contact with either the player or the ground.

The USAFootball tackling framework contains six phases designed to aid in performance of a safe tackle. This frame work focuses on both the coach and the player and is designed to address the specific needs of the athlete at their individual phase of learning the technique. The Heads Up Framework recommends:

1. Head placement across the front of the target.
2. Achieve contact in the appropriate strike zone.
3. Make contact with the shoulder rather than the head.
4. Develop and maintain strong fundamental skills.
5. Advance the technique from static to dynamic movements through appropriate drilling.
6. Progress the drills from static to dynamic situations to mimic game situations while maintaining safety.

These six critical components are taught along with other techniques to improve the chances of bringing the target to the ground during competition, but in theory do not aid in reducing contact to the head of the tackler.

Tackling Based Injuries

Cervical Angle and Cervical Spine Injury

In 1975, spurred by 12 football players in Pennsylvania and New Jersey suffering severe cervical spine injuries, The National Football Head and Neck Injury Registry was established[21]. The initial report from this registry indicated, "1) the improved protective capabilities of modern helmets accounted for the decrease in head injuries…, 2) the improved protection of the head led to the development of playing techniques that used the top or crown of the helmet as the initial point of contact and, 3)these head-first techniques placed the cervical spine at risk for serious injury."[44] Following these statements rule changes were created to ban crown of the head or spear tackling. Bony neck injury, while greatly minimized through these rule changes [45], still occurs at a rate of 1.10 injuries per 100,000 high school and 4.72 injuries per 100,000 college football participants [10]. Flexed cervical postures on contact are the cause of most catastrophic cervical injuries [46]. Thirty degrees of cervical flexion places the vertebral segments in line, removing the normal cervical lordosis, causing the total force of the impact to the crown of the head to be absorbed by the vertebral discs and vertebral bodies (**Figure 3**) [47]. Experts in football tackling technique have recommended a heads up posture to

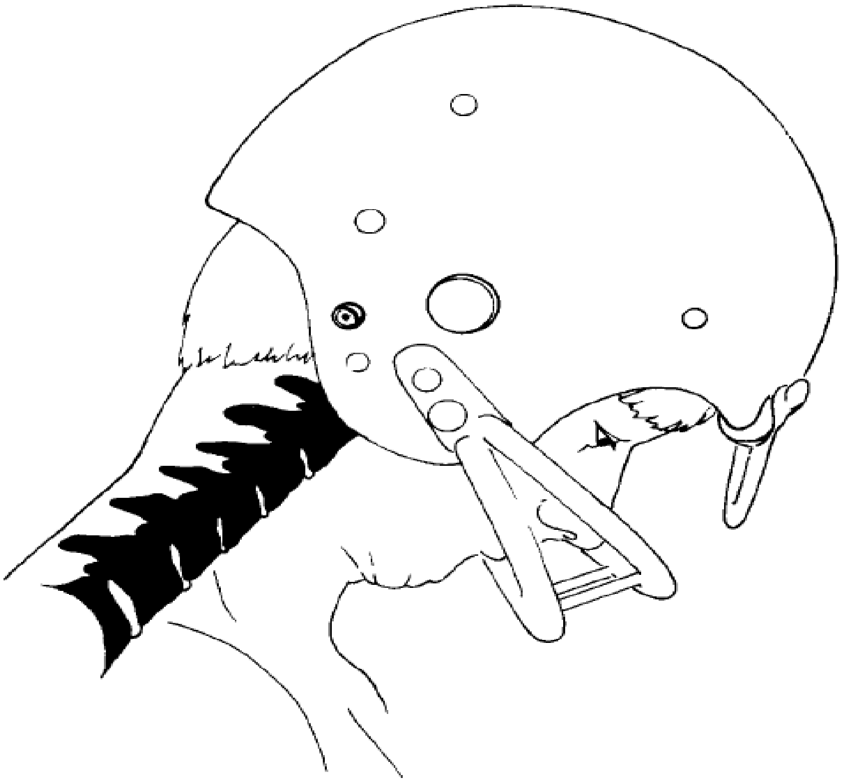


Figure 3. 30 degrees of cervical flexion creates an aligned cervical spine causing all axial force to be absorbed by the body of vertebrae (Torg, 1990). Reprinted with permission.

minimize crown of the head contact that would place the player at risk of an axial loading of the cervical spine [45].

Prior to 1976 an average of 110 cervical spine fractures per year occurred in college and high school level football. Film and epidemiologic evidence pointed toward axial loading of the spine as the primary mechanism of this injury [21]. Tackling with the crown of the head, or spear tackling, was common practice at this time. Identifying spear tackling as the cause of axial loading of the cervical spine led the National Federation of State High School Association (NFSHSA) and the National Collegiate Athletic Association (NCAA) to implement rule changes to eliminate spear tackling. Within eight years of this rule implementation the number of injuries was reduced to an average of 42 per year [21]. Rule changes have been shown to be capable of changing behavior patterns in football.

There are many different injuries that can occur in the cervical spine due to axial loading in football. These injuries occur when the compressive forces on the relatively small bodies of the cervical spine are subjected to large compressive forces that exceed the failure limit of the spine[48]. The upper limit of force capable of being absorbed without boney injury is indicated to be approximately 4454 N[49]. Atlas and axis fractures resulting from axial loading injuries can also cause instability of the spine[50]. Axial loading can cause injuries other than fractures including root and brachial plexus neuropraxia, cervical sprain, intervertebral disk lesions and transient quadriplegia [51]. Many different areas can be injured with a large range of severity when making contact with the crown of the helmet in football.

Cervical cord neuropraxia is a condition that can also be caused by an improper cervical spine position on impact. Cervical cord neuropraxia or transient quadriplegia is a condition characterized by temporary pain, paresthesia and/or motor weakness in more than one extremity that is temporary and experiences a complete resolution. This condition can be caused by hyperextension, hyperflexion or axial loading of the spinal column[52]. Recent data demonstrates a rate of 0.17 injuries per 100,000 participants in high school and 2.05 injuries per 100,000 participants at the college level[10]. Poor tackling mechanisms can allow the head to become hyper-flexed, hyperextended or allow for axial loading, all of which may cause cervical neuropraxia.

Cervical spine injury continues to be an injury threat despite its drop in prevalence since the 1970's. New recommendations for tackling styles to minimize concussion risk should be evaluated for their effect on cervical angle. USAFootball tackling style teaches a very direct statement to keep the head and shoulders up, effectively maintaining the cervical extended posture if performed correctly [16]. Rugby style tackling takes a lower aim point which may make it more difficult for the tackler to maintain an extended cervical spine [29]. Prior to recommending youth athletes adopt a new tackling mechanism it is crucial that we understand this styles effect on the cervical spine angle during tackling. It does not serve the football community well to attempt to eliminate concussions while potentially increasing the risks for cervical spine injuries.

Sports Related Concussion

The term Sports Related Concussion (SRC) is often used synonymously with mild traumatic brain injury (mTBI). According to the consensus statement produced by the Zurich International Conference on Concussion in Sport:

> "Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include:
>
> 1. Concussion may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an ''impulsive' force transmitted to the head.
>
> 2. Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, symptoms and signs may evolve over a number of minutes to hours.
>
> 3. Concussion may result in neuropathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.
>
> 4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. However, it is important to note that in some cases symptoms may be prolonged[53].

Symptoms of Concussion

Symptoms of concussion are highly variable due to the multiple regions of the brain involved. The clinical domains of concussion include the appearance of symptoms in somatic, cognitive and emotional domains, physical signs, behavioral changes, cognitive impairment, and sleep disturbances [54]. After injury, individuals may have symptoms of memory loss, emotional lability, depression, balance issues, difficulty with concentration and sensitivity to light and noise among many others. While loss of consciousness may be a symptom, it is no longer regarded as the primary diagnostic criteria. A multifaceted approach including evaluation of self-reported symptoms, mental status tests, neurocognitive assessments and evaluation of postural control is currently recommended [55]. The management of concussion is recommended based on current symptoms as well as modifying factors unique to each injury [54]. Symptoms of a concussion may evolve over hours to days after the initial impact making severity difficult to determine initially.

Mechanics of Concussion

The primary mechanisms of concussive injury are thought to involve linear and rotational acceleration, though the relationship between these variables and the symptoms of the injury remain unknown. Throughout the 1950s and 60s, translational acceleration caused by changes in linear acceleration was theorized to be the primary cause of concussive injury [56]. Later studies reduced linear acceleration's contribution to 50% of the responsible forces during concussive blows [57]. The pressure gradient caused by the rapid deceleration of the brain is believed to be the mechanism of injury resulting from impacts with high levels of linear acceleration. Focal injuries, where only a specific and well defined area of the brain is affected, have been demonstrated to be caused by the effects of linear acceleration, while more diffuse injuries may be caused by rotational acceleration [58]. Rotational acceleration causes shear and tensile strain [59] on the brain tissues which have been shown to cause more diffuse injuries as well as injury to deep brain where cortical injury is not present [60–62]. Currently, calculations such as the Head Injury Criterion (HIC) and Gadd Severity Index are used to attempt to identify the contribution of each factor in concussion [63]. These combination measures of linear and rotational acceleration have shown promise at increasing the predicative capabilities of head acceleration measurement to detect concussions [64]. Because of the variability injury profiles, the frequency of concussions, and the variable nature of impacts, the exact contribution of these two forces are currently not completely understood.

Effects of Concussion

Physical impact effects the brain in a multitude of ways including: non-uniform compressive stress, brain lag and rotation coup-contrecoup impact injury [65] and acceleration/deceleration injury [66]. These mechanisms can cause a number of physical changes to the brain tissue and its supporting functions that can lead to neuronal swelling, sterile inflammation, axonal disruption, and autonomic and metabolic changes leading then to functional deafferentation of the cortex [67] as well as changes in the brainstem in cases of loss of consciousness [68]. Diffuse axonal injury (DAI) is damage to the axon as a result of mechanical loading during TBI [69,70]. DAI includes mechanical disruption of axonal cytoskeleton, altered axonal transport[71], axonal swelling [72] and other changes that may include proteolysis, die-back disconnection and reorganization [73]. Decreased cerebral blood flow has been described in adults immediately after insult, this reaction may be delayed in children and young adults [74], which can further augment the excitotoxic damage that occurs with injury [75–77]. All of these individual conditions along with the multitude of structures effected results in the highly variable presentation of concussive injuries.

Metabolic changes can also be seen in brain tissue post injury. N-acetylaspartate, creatine and choline levels in the brain are altered after a concussive injury. These alterations often times peak at three days post injury and may provide objective diagnostic criteria as well as explain the origin of second impact syndrome [78]. Neuroinflammation, while not yet fully understood, may be a pathway that influences the long term effects of TBI. Post-traumatic neuroinflammation is indicated by increased glial cell activation, leukocyte recruitment, and upregulation of inflammatory mediators [79]. Microglial activation while helpful can become over-activated, inducing detrimental neurotoxic effects from multiple cytotoxic substances including pro-inflammatory cytokines (e.g. interleukin (IL)-1b, tumor necrosis factor-a (TNFa), and interferon-c (IFNc)) and oxidative metabolites (e.g. nitric oxide, reactive oxygen and nitrogen species)[80]. Each of these actions can take place in multiple regions of the brain, adding to the complexity of a concussive injury.

Multiple portions of the brain can be affected by concussion, which may be an explanation for the multiple and variable effects of this injury. The region or regions affected can be inferred by associating the symptoms with the region responsible for performing that activity. Frontal lobe injury is common in TBI due to the nature of head impacts. Injury to the frontal lobe results in reduced neurocognitive function including executive function [81] cognitive processing, speed, verbal fluency and memory [82]. Temporal lobe involvement can lead to deficits in memory and language. Testing of visual and verbal memory has indicated that 75% of patients after mTBI demonstrate medial temporal lobe abnormalities on PET and SPECT imaging that was correlated with decreased memory [83]. Changes can also occur in the subcortical systems of the brain. Injury to the hypothalamus may result in autonomic dysregulation leading to decreased heart rate variability during exercise [84]. Other areas of function impacted can include altered sleep/wake cycles [85], altered appetite [86], difficulty with thermoregulation [87] and diabetes insipidus [88]. Although the pathogenesis of post traumatic headache is not defined, it may be caused by disruption of the trigeminal system [89]. Post traumatic headache in children is present in 2.3% to 6.8% of cases of TBI in children [90,91]. Involvement of the cerebellum may be linked to balance disruption that commonly occurs in patients with TBI. All regions of the brain can be affected post-concussion, making concussion a wide ranging insult to the brain.

Pediatric Head Injury

Pediatric head injury should be considered separately from the adult brain due to the differences in their structure and the ongoing development of the young brain. The pediatric brain differs from that of the adult brain as neuronal systems continue to develop typically up to age 21 [92–95]. The areas of the brain responsible for primary senses and motor skills are thought to be developed by age 4, with language continuing to develop through age 10. The areas of the brain involved in abstract processing, reasoning, judgment, emotion and other functions primarily controlled by the frontal areas do not fully develop until the late teenage years into the early 20s [96]. During childhood and adolescence a large increase and selective culling of grey and white matter occurs dependent on the activities and experiences of the individual [97]. This activity is responsible for alteration of the areas of the brain that continue to develop during this critical period [98]. The growth of grey and white matter during this period can be affected by the direct injury as well as the cascades that follow the initial injury. Injury in youths may affect the critical periods of development ongoing at this time.

Children with concussion often experience the same symptoms as adults with concussion. Headache, fatigue, dizziness and taking longer to think are often present during initial evaluation. Symptoms of sleep disturbance, frustration, forgetfulness and fatigue typically developed in later follow up [99]. Occurrence of somatic symptomology falls in line with adult experiences. These reported symptoms were most evident at initial evaluation and had resolved by 12 month follow up. Cognitive symptoms did not tend to peak until a 3 month assessment and remained above those of a non-injured group through the end of a 12 month follow up. Children who had experienced loss of consciousness, acute CT scan abnormality, parenchymal lesion on MRI, hospitalization, motor vehicle related trauma, and injuries to areas other than the head reported higher levels of post concussive symptoms [100]. Disturbances of somatic, cognitive and emotional domains appear in pediatric concussion as is seen in adults.

Effect of Cervical Strength

Cervical strength has been recommended as a potential risk factor and preventative mechanism for concussion. Cervical strength works as a connecting mechanism, tying the cranium to the thorax creating a larger mass object which provides greater inertial resistance to an impulse[101]. Studies have indicated females experience greater head acceleration than males in response to an impulse during soccer participation[102]. This response may be explained by significantly less isometric cervical strength and neck girth in females and youth athletes[36]. In soccer heading the participant is often aware of the impending impact and is able to contract the muscles of the neck which has been shown to decrease inflection in response to an impulse[35,103]. In sports in which the impact is not anticipated there is no relationship seen between isometric strength and concussion risk[37,104]. In these sports, cervical stiffness may be a more appropriate measure of concussion as the rapid nature of the impulse[23] is faster than typical reaction time[105].

Motor Learning

History of Motor Learning

Motor learning is a set of internal processes associated with practice or experience leading to relatively permanent changes in the capability for motor skill [106]. Motor learning research seeks to understand the mechanisms and principles involved in learning movement and motor skill.

Since the astronomer Bessel first wondered why some astronomers were able to more accurately measure star transit times, scientists have been concerned with the mechanism in which people learn to become skilled in movements[107]. There have been many theories posited to explain the mechanism in which people learn to move. Nikolai Bernstein [108] explained the phenomena of improved skill in hammer swinging through the learner freezing the degrees of freedom in a movement. This allowed a learner to focus on particular aspects of a movement while locking out movement in other areas. This process then moved to releasing and reorganizing these degrees of freedom as the learner became more skilled. Finally, the learner was able to exploit the mechanical and inertial properties of the body to improve their movement. Long lost behind the wall of the Soviet Union this work had not been readily discussed until the fall of the Soviet bloc. More recently this work has been challenged [109] as additional research has postulated that the maintaining the static position of the joint still requires active control to stabilize the joint, thus requiring just as much attention to control as if the joint were in motion.

A theory on the interplay of control and movement was proposed by Jack Adams [110]. His closed loop theory organized the mechanisms of feedback, memory and perceptual traces to explain how skilled movement is developed and improved. This theory states that we store memory traces of the sensory input regarding performance of the movement. After the movement is performed the perceptual trace of the movement is compared to the memory trace, providing the learner with feedback that is then interpreted by a control center which alters the memory trace. Research indicates providing random practice of the involved skill, creating contextual interference, improves retention and transfer of the skill especially in high complexity tasks[111]. This theory’s strengths include an emphasis on the importance of practice and feedback, but fails to account for contextual interference improving learning.

Schmidt [112] elaborated on a proposed schema theory of learning which posits the learner develops a general idea or schema of the mechanism needed to perform the movement and then adapts the performed pattern to the situation as needed. When learning a novel task or information the participant is better able to remember those aspects that they are already familiar with or have a context in which to attach the new information[113]. This theory helps to remediate the issue of storage capacity and novel movements that plagued earlier theories. In the closed loop theory each movement requires its own memory trace with no ability to adapt. This would cause a near infinite number of memory traces to be maintained and accessed by the brain for creation of motor patterns. By creating a schema, or general pattern of movement that is adaptable, the schema theory minimizes the space needed for movement patterns.

New advances in neural networks have provided combined biological and computational theories of motor learning. These theories utilize computational strategies to model the neuronal involvement in learning[114–119]. These systems are able to calculate the interaction of simulated neurons in silico based on physiological properties. Individual neuron connections and reactions can be modelled and combined into large systems of neurons that mimic simple learning. Neural networks are able to remember and implement movements and decisions based on the training they receive. Advances in this field have created a better understanding of the interplay involved in motor learning at a neuronal level.

Effect of Concussion on Neural Processes of Motor Learning

Concussion is a diffuse and highly variable injury due to multitude and diverse actions of areas of the brain that may be impacted by the injury. Short term symptoms of concussion can be highly variable but often include decreased balance [120], difficulty with concentration, and coordination [121]. The ability to alter motor patterns during this time period may also be diminished due to involvement of the areas of the brain utilized in motor learning [122]. Acute response to concussion shows slowed fine motor dexterity, reaction time and movement times that positively correlated with increased corticospinal inhibition 48 hours post-concussion [121]. Research suggests the presence of a slight metabolic imbalance between GABA concentrations in the primary motor cortex of concussed athletes that is absent in non-concussed controls [123,124]. The imbalance of these neurotransmitters may inhibit the long term potentiation (LTP)/long term depression (LTD) of the synapses required for learning.   The effects of concussion on the ability to develop new motor patterns may create a situation in which athletes are unable to correct the movement patterns which put them at risk for concussion after they have suffered a concussion.

Recently increased emphasis has been placed on the long term consequences of concussions. The dysfunction of the brain during a concussion has been thought to be primarily functional [53] and metabolic [125] with typically no structural damage in the short term. Studies have identified multiple effects of concussion that are seen years after retirement from participation. Included in these involved areas may include the areas required to develop motor learning. Research utilizing transcranial magnetic stimulation found repeated concussions created persistent elevations of GABA mediated intracortical inhibition in M1 which was associated with suppressed LTP/LTD-like synaptic plasticity and reduction in implicit learning as indicated in decreased performance on a serial reaction time test [126]. Changes in neuron connection indicated by fractional anisotropy measures are also seen in retired athletes with a history of concussions [127]. These changes were primarily noted in the fronto-parietal networks and the frontal aspect of the corpus callosum. White matter anomalies have also been found in former athletes with a history of concussion. These abnormalities were significantly associated with a decline in episodic memory, lateral ventricle expansion and decreased performance in motor learning tasks [128]. Athletes with a history of concussion show a thinner cortex of left anterior cingulate cortex, orbital frontal cortex, medial superior frontal cortex, the right central sulcus and precentral gyrus relative to healthy controls [129]. Overall the imbalance of neuroreceptors involved in learning, decreased connectivity within the brain and decreased white matter may result in situations in which it is difficult to alter the movement patterns of an athlete due to difficulty learning new motor patterns.

After being cleared to unrestricted play, suffering a concussion may also lead to an increased risk of musculoskeletal injury across the entirety of a season as well as across multiple seasons. When data analysis is limited to 90 days post return the increase in injury risk doubles[130–132]. At 180 days this increased risk remains approximately doubled but may in fact be higher[131,132], and continues on through the rest of the playing season[131–133]. These results indicate the effects of concussion may last through the season. A retrospective survey of American football athletes has also found an increased risk of injury across a career of participation, indicating this increased risk may not only effect the athlete over the current season, but may follow the athlete through their career[134]. Some research has linked the affect of variables related to neurocognitive testing to the safety of athletes when returning from concussion[135]. Decreased scores both in baseline and post-injury time points may put the athlete at increased risk of musculoskeletal injury, indicating those at risk for concussion may be at risk of injury overall[136]. History of a concussion has been shown to be related to continued poor performance on neurocognitive testing after the resolution of symptoms as well as decreased postural control long after resolution of symptoms[137]. Concussions in both the long and short term can increase an athlete's injury risk, leaving prevention of injury as a valuable goal rather than rehabilitation alone.

Motor Learning Stages

The stages of motor learning have been described functionally as the process of movement pattern acquisition from an unskilled and uncoordinated movement to a skilled, autonomous movement [138,139]. In the Cognitive Stage, the learner begins to internalize the general rules and procedure of the movement. The learner will make large and widely varying mistakes and requires large amounts of working memory be focused on the activity [140]. This phase has also been described by further breaking down the activity by rate of improvement: fast learning and slow learning phases [141]. This description identifies the rapid learning that takes place within the training session and the slower learning that takes place between training sessions. With practice and feedback the learner enters into the Associative Stage. In this stage the learner begins to make fewer mistakes and requires less cognitive load to perform the activity. After additional practice and feedback the learner may enter into the Autonomous phase of learning. In this phase the learner has mastered the skill, makes very few and minor errors and requires little to no working memory load be focused on the activity as the more automatic centers of the brain have taken over control of the activity [139,142].

Learning has also been broken down into four stages from a neurological standpoint, based on changes in performance and brain activation. The first portion is referred to as the fast or early stage, during which improvement in performance takes place rapidly during practice. The second, slow stage refers to the improvements in performance between several sessions. During these time periods the primary motor cortex (M1) is activated but remains below the level of activation seen in later, more skilled practice [143]. The prefrontal cortex, particularly the dorsolateral prefrontal cortex, is responsible for memory and association of visual cues and motor commands [144]. Activation of the cerebellum is primarily located in the cortex, shifting toward the dentate nucleus during early practice [145]. Both the cortico-cerebellar and cortico-striatal systems [146] and presupplementary motor area (pre-SMA) [147] are active during early learning. The cortico-cerebellar and cortico-striatal systems are active during the fast and slow phases and remain active during what is believed to be the activity responsible for consolidation of motor learning [146]. The third phase is referred to as the consolidation phase [141]. This phase represents the spontaneous improvements that occur for the first 4-6 hours after practice. During this time the primary regions of activity shift from the prefrontal regions of the cortex to the premotor, posterior parietal and cerebellar cortex structures [148]. The fourth or automatic stage requires little cognitive resources and is resistant to interference from outside activity and the effects of time. This phase shows higher activation of M1[143], supplementary motor area (SMA) [147], continued activation of a cortico-cerebellar pathway system [146] and minimal activation of the frontal cortex [144]. This progression of motor learning from unskilled to skilled allows for increased automaticity of the movement profile.

Intrinsic vs Extrinsic Feedback

Feedback on movement actions can be received from sources either intrinsic to or extrinsic from the learner. Intrinsic feedback is received from within the body as kinesthetic, tactile, auditory and visual cues regarding movement. These intrinsic senses are active at most times unless otherwise isolated [149]. Intrinsic feedback is important for retention of movement, as inattention to it is thought to be the basis of the guidance theory, which is discussed later. The learner can also be given feedback from extrinsic sources, often referred to as augmented feedback, through many of the same mechanisms. The majority of research has been performed in verbal [150,151] and visual feedback [152] but tactile and auditory feedback [153,154]can be provided as well. Extrinsic feedback can be ineffective if it merely reflects the intrinsic feedback provided by the senses [155,156]. Feedback on movement outcomes and performance is available from many sources.

Augmented Feedback

Augmented feedback is defined as information provided from an outside source that may or may not be altered to enhance the value of the content [106]. When providing augmented feedback the information can be presented in either knowledge of performance or knowledge of results. Knowledge of performance (KP) is information provided regarding the one’s own physical performance of the action [157]. Knowledge of performance has been shown to be effective in altering movement patterns in different contexts including basketball free throw [158], off hand throwing [159], soccer throw-ins [160] and drop jump landing [6,161,162]. Knowledge of results (KR) is information regarding the outcome of the movement. Aside from practice, KR has been regarded as the most important factor in learning [151]. Knowledge of results has been utilized in many areas across the breadth of motor learning [4,150,163]. Examples of such are success at hitting a target with a throw or making contact with a pitch while swinging [164–166]. Despite being distinct in definition, it is unclear if the fundamental mechanisms between KP and KR are different [151]. Often the distinction can be blurred between whether the feedback should be considered KP or KR. This is exemplified in gymnastics in which the performance form is the result goal. Augmented feedback is divided into two categories, information about the movement, KP, or information about the outcome, KR, yet sometimes the division is unclear.

Performance versus retention

In early studies of motor learning, the outcome of the movement at the end of training was analyzed for the effect of the treatment [110,167]. Research in the field began to recognize that true learning testing required maintaining the change in skill. The field began to identify retention of the task skill as more representative of true learning than performance at the end of training [151]. The performance of the skill after a time period in which no training of the skill was provided, known as retention, was thought to indicate the true level of learning attained. Additionally attention was given to the ability of the learner to transfer the knowledge of that skill to new yet connected movement patterns. A paradigm shift ensued in which retention and transfer testing became considered best practice for assessing true learning of the new skill.

Identifying the importance of retention and transfer altered the understanding of schedules of feedback. Schedule of feedback refers to how often augmented feedback is provided to the learner. Prior to the transition to the use of retention and transfer tasks to evaluate learning, it was suggested that increased feedback improved learning [112,152,163,167]. Once the focus changed to retention and transfer of the skill, this paradigm no longer stood. Researchers found that providing less feedback was beneficial to true learning [166,168] (**Figure 4**). This breakthrough leads to the discovery of the guidance hypothesis [151,169]. This hypothesis states that with constant feedback the learner will become dependent on the feedback and not attend to the intrinsic feedback provided by their body as well as not internalize control of their performance, expecting feedback to be provided. The guidance hypothesis provides a framework that defines the effects of feedback schedule on retention and transfer tasks.

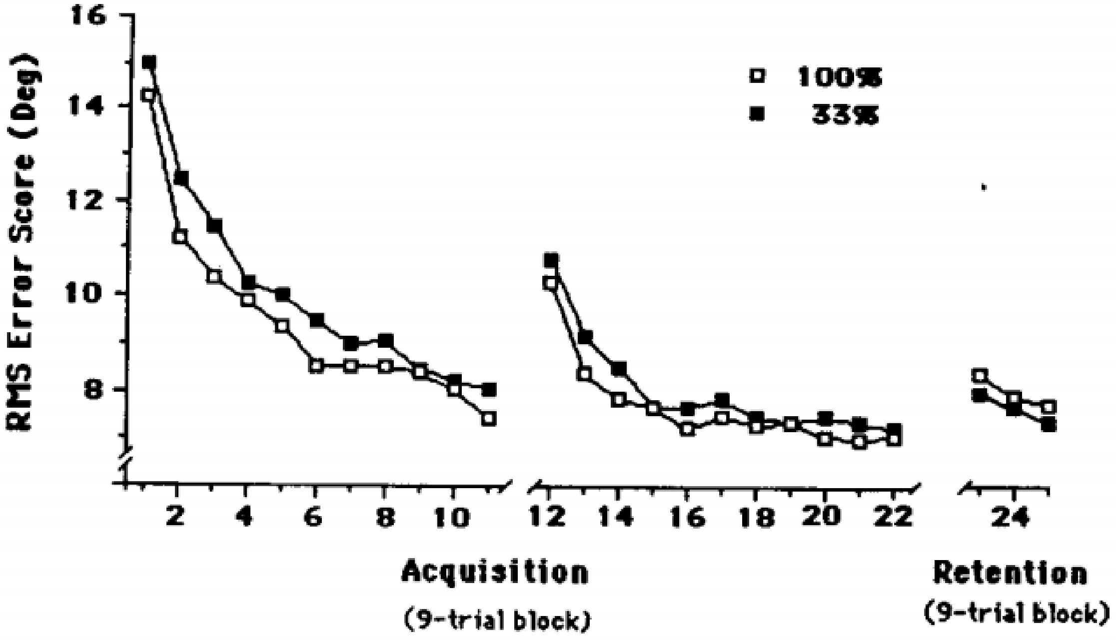


Figure 4. Averaged root-mean-squared error for the two acquisition KR-relative frequency conditions for Day 1, Day 2 and Retention phases. (Winstein and Schmidt, 1990) Reprinted with permission.

Feedback Schedules

While many studies identifying the effects of simple skills have shown large blocks of training are more effective in improving retention, smaller blocks have been shown to be more effective in more complex skill learning. Previous research has indicated the optimal block size to be five trials per block during complex skill learning [170–172]. Participants continue to make improvements over a longer time frame when providing feedback for more complex skills. When performing a complex ski simulation task participants continued to see improvement with up to six sessions of training [173,174]. In this study participants performed six 90 second training regimens per treatment day, by the end of training all participants had performed 36 training cycles. More complex skills require longer training and moderate block size to maximize the effect of the feedback technique.

Further research into the effectiveness of feedback schedules helped to develop the faded feedback paradigm [175,176]. This mechanism provides a tradeoff between the need for feedback during the early phases of learning and the need for lower amounts of feedback to properly retain the learned skill. Faded feedback provides higher levels of feedback during the early stages of learning when the learner is still developing and understanding the movement pattern then decreasing the frequency of the feedback as training continues to improve retention of the skill. Research indicates providing higher frequency feedback in early stages and moving to less frequent feedback later is more effective in creating long term retention than constant or reverse fading [175]. As the performance improvement begins to plateau, faded feedback begins to decrease the feedback schedule to encourage the learner to attend to their own performance and begin to rely on intrinsic feedback rather than external feedback. Faded feedback does not, however, provide superior retention over 100% feedback in children [177]. Feedback provided on every trial was found to be more effective in young children (m=10 years) in a reaching task. Children who received 100% feedback had improved performance both during acquisition of the task and at a no feedback retention test. Young children do not respond to faded feedback in the same manner as adults, performing better with constant feedback.

Focus of Attention

Focus of attention is an important factor in the retention of skill learning. Attention of the learner can be either focused on the action of the body part, internal focus of attention (IFA) or on the action of an implement or item that is not part of the body, external focus of attention (EFA) [178,179]. Research on providing EFA has shown improved performance and no effect of the guidance hypothesis, allowing continued improvement through high frequency feedback with no decrement in retention [180–183]. This change may be due to EFA not altering the existing motor plan directly. Rather than specifically indicating the movements needing to occur, EFA allows the learner’s body to utilize the existing motor plan to achieve the goal movement [181]. EFA allows for the provision of feedback on every trial to maximize adaptation during acquisition without a decline in retention typical of high frequency feedback.

Motor Learning in Children and Adolescents

When providing feedback to young and new learners the information should be simplified to better direct the learner to the key aspects of the movement. Young and new learners are often incapable of determining the most essential portions of the movement and can be overwhelmed by detailed instructions [184–186]. Adolescents and children perceive and process information slower[187–190] and benefit from less precise knowledge of results feedback [163]. fMRI study of activation during implicit learning shows different cortical activation patterns and magnitudes in children when compared to adults [191]. Young learners utilize different strategies to process information in tasks requiring visuo-spatial working memory [192], object recognition memory [193], verbal learning [194], copying spatial patterns [195], and higher level attention focusing [196,197]. Children achieve more accuracy and consistency across trials of a discrete arm movement with 100% feedback over 62% feedback, indicating children do perform at a higher level with continued feedback [177]. Children and adolescents process information and utilize working memory different than adults; therefore it is necessary to provide children with smaller chunks of information and more frequent feedback to facilitate retention of motor learning skills. These differences make it essential that when determining the effectiveness of a motor learning treatment the mechanisms and methods be specifically studied and developed for this age group.

Video Feedback in Adolescents

Video feedback may provide an effective means to integrate feedback into youth performance training. Video feedback has been used by coaches, trainers or medical professionals to help alter the motions of athletes [6,162,198], in the rehabilitation setting [199–203] or in human performance [204,205]. Video feedback can assist in changing incorrect form or potentially injurious mechanics to a movement pattern with less risk of injury. Video feedback can assist in changing motor patterns that may need to be altered due to incorrect form or potentially high injury risk mechanics. Current research has been performed to alter the motions most likely to cause knee injury, [162,198] improve swimming technique [3], golf swings [4], tumbling performance [206] basketball performance [5], and tennis serves [7,207]. Video feedback can provide a mechanism to improve youth motor performance in a variety of tasks.

The model type utilized can alter the effectiveness of the feedback being provided. When providing video feedback, the facilitator must be aware of the effect of the model used to exhibit the proper execution of the skill. The model provides a visual blueprint for the learner to mimic as well as to draw inferences, either explicit or implicit, regarding the proper movement pattern. Several investigations have been conducted utilizing augmented video feedback to improve movement patterns in adolescents with varying models [14,208–212]. The models typically presented and identified through a search of the feedback literature are: Self-Observation Feedback Model, Expert Feedback Model, Self plus Expert Feedback Model and Self as Expert Feedback. Each of these models provides a different type of information to the learner. Self-Observation provides video of only the learner, Expert Feedback provides only video of the expert level performance, Self combined with Expert provides the learner with video of themselves and an expert, and Self as Expert models show the learner performing at their best. Each of these models can be used to provide video feedback to improve performance.

Self-Observation Feedback Model

The use of Self-Observation during video feedback involves providing the learner with a video playback of their current performance of the skill [15]. This type of feedback provides no visual information on the desired pattern and thus requires any information on this pattern to be provided through another mechanism. Self-Observation provides the participant with current information on performance, but lacks direction toward the goal pattern. This mechanism may be effective when the learner is aware of the desired movement, but may lack usefulness during instruction of movement patterns that have an imperfect concept of the desired movement pattern.

The effectiveness of Self-Observation feedback is not consistently supported in younger populations. Clark & Ste-Marie [14] did not find a significant difference in the consistent accuracy of a swimming stroke when provided with self-observation feedback. They found no difference in immediate post-test performance accuracy between subjects and a control group after six consecutive sessions of the subject reviewing video performing the designated swim stroke from the previous session. There was no difference between the groups in the 24 hour retention test. In comparison, Parsons & Alexander [210] analyzed volleyball players' lower extremity range of motion during a jump landing skill. They found the participants improved their landing motion towards the instructed motion pattern greater than the control group in ankle range of motion in the immediate posttest and knee flexion and hip flexion at four weeks. The participants were also given verbal feedback during the testing phases in the form of reminders of the proper landing form. These results might be influenced by the effect of verbal feedback. Clark & Ste-Marie [14] provided no verbal feedback, while Parsons & Alexander provided on going corrective verbal feedback during the course of the research. Based on these preliminary findings, the effectiveness of a self-observation video has been shown to have mixed outcomes in the adolescent aged population.

Expert Only Feedback

Expert only video feedback involves providing the learner with video of an expert's performance only. This video type allows the learner to see the form they have been instructed to perform. This feedback type is often referred to as modeling as the expert provides the learner with a model to be imitated. True feedback to the learner must come in another form as the expert only feedback provides them with no information regarding their performance. Studies in modeling have repeatedly identified the effect of the verbal feedback and verbal rehearsal as the primary factors in the success of expert only feedback [213–215]. Form performance of the skill can be positively affected by expert only modeling [216,217]. Expert only video feedback may not be effective without an additional mode of information providing information on the participant's current performance.

Self Plus Expert Model Feedback

Self-observation plus expert model feedback may be advantageous over other forms of feedback. This feedback model provides the learner with information on their current performance plus information on the correct performance of the skill. This method allows the learner to identify the differences between their current performance and the expert model. Self-observation plus expert model has been indicated to be effective in a wide range of age groups. Baudry, Leroy, & Chollet [208]analyzed the ability of 16 gymnasts to maintain shoulder, hip and foot alignment through four phases of a pommel horse routine. The feedback group was provided side by side video of themselves and an expert model performing standard circles on the pommel horse. They found significant improvements over a control group through the progression of the sessions and at post-test in all phases of the motion. Onate [162] also found significant improvement in groups provided with a self-observation plus expert feedback model in a jump landing movement. These college-age participants were able to decrease knee angular displacement and peak vertical forces on landing during a drop vertical jump [162]. These two studies indicate that self-observation plus expert models may be effective in both youth and college age physically active participants.

Self as Expert Feedback Model

Self as Expert Feedback utilizes either portions of the movement that are edited together in discrete skills (e.g. baseball pitching) or a repeated iteration of the correct form in continuous or serial skills (e.g. swimming). The provision of Self as Expert feedback utilizes the positive effects of self-observation by allowing the participant to personally identify with the feedback model as well as providing proper performance information similar to expert modeling paradigms. This combination appears to be effective in improving movement patterns in adolescents. This self-modeling technique may be limited by not allowing the participant to determine the difference between current performance patterns and goal patterns.

Clark & Ste-Marie [14]and Ste-Marie et al. [211] both indicate a positive effect of Self as Expert feedback. The continuous swimming skill analyzed by Clark & Ste-Marie (2007) showed increases in performance accuracy in the post-test completed at the end of six days of practice with feedback and at the 24 hour retention test over controls and self-observation. Ste-Marie et al. (2011) found increases in performance accuracy of a serial trampoline skill in test routines over control routines in the 24 hour retention test after three sessions of self-modeling feedback. This mechanism was also found to be effective when combined with an expert video, self as expert feedback was as effective as self-observation [15]. Both groups of investigators found significant differences in performance accuracy when utilizing Self as Expert feedback.

Law & Ste-Marie [209] found no significant differences in performance outcomes and performance form ratings in a figure skating jump performance over controls at a one week retention test after three weeks of training when utilizing self-modeling feedback. Winfrey & Weeks [212] also found no differences between Self as Expert and control groups in a balance beam performance skill. This study utilized the same video created at the beginning of the test for each of the six training weeks. These results indicate the effectiveness of Self as Expert feedback in serial and continuous skills may not carry into more discrete skills.

The four mechanisms presented here provide evidence of the effect of model type on the retention of video feedback. Of the four model types presented, self-observation plus expert model showed successful retention of the instructed skill in each of the studies identified in physically active adolescent aged populations. Providing the learner with an image of their current performance and the goal performance may minimize the processing needed to understand the adjustments needed to current performance to achieve the desired movement profile.

Assessment & Outcome Measures

Visual Estimation

Visual estimation of poses and activity while common in both performance and feedback should be utilized with caution and an understanding of the variability of the measures. While visual estimation of movement patterns is standard practice in coaching[218], the use of additional measurement techniques has increased [219–222]. Visual estimation of joint motion has been reported to be highly variable and with limitations in its accuracy[223–226]. Despite these concerns visual estimation of movement requires no equipment and can be performed immediately without data processing. This makes visual estimation of movement a commonly utilized mechanism. Utilization of rater training and standardized procedures has been shown to improve rater agreement in dynamic movements[227–229]. Combined feedback from visual estimation and other sources are common in feedback mechanisms and with training can be reliable.

Assessment of Biomechanical Variables

Quantification of biomechanical variables can be performed utilizing different systems, each with their own advantages and disadvantages. Two Dimensional systems utilizing video cameras can be relatively inexpensive, portable, and flexible, while being minimally invasive to quickly and easily provide feedback to the learner. Online or computer based systems tend to be more expensive and require greater technical proficiency in their use. Online systems can utilize active or passive marker systems or accelerometers. Active 3-D marker systems utilize an array of video cameras and LEDs to track body segments through a pre-calibrated volume. Passive optical 3-D systems utilize retroreflective markers and an array of cameras that project infrared light into a pre-calibrated volume. Passive electromagnetic systems analyze the movement of magnetic markers through a magnetic field. Accelerometer systems track the motion of body mounted accelerometers through which movement can then be extrapolated. Online systems require post processing to provide feedback to the learner which can be time consuming and technical.

Two Dimensional Systems

Two dimensional (2-D) motion capture systems can be as simple as a video camera alone or as complex as multiple camera systems tied together to provide multiple angles. These systems are often easy to operate and can provide immediate feedback to the learner. Joint angles and distances can be calculated utilizing simple software that is available in open source (Image J) or in highly sophisticated software (Dartfish), dependent on the options available. Collecting joint angles from 2-D data can be performed in a number of ways. Software packages are able to determine the angle created at the intersection of 2 lines. These systems have shown to be reliable and valid in measurement of knee valgus [219,230,231]. A technique that has also been utilized in the measurement of joint motion is manual digitization [232,233]. In this process specific landmarks are identified and their location within the frame marked. The relative location of these markers is then used to calculate the resultant joint angles. Manual digitization can also be utilized to determine distances between landmarks [234,235]. Specifically within the spine the results of research has shown mixed results. Utilizing surface skin markers and 2-dimensional video, these studies have found good reliability [236] but lack of correlation to biological measures [237].

Three Dimensional Systems

Active and passive marker systems of 3-dimensional motion capture work in much the same way and are currently the gold standard in motion capture. Both systems utilize a series of stationary 2-D cameras to record body worn markers through a volume of space. These markers are tracked by a computer system that constructs a 3-D representation of the volume from the 2-D view of the camera system. Anatomical segments are then created utilizing the 3-D locations of the markers. Active marker motion capture systems utilize a series of illuminated LEDs placed at anatomical landmarks to track the movement of the subject. These systems can place a restriction on the number of markers used and require a power source on the subject. Active systems can be accurate to 0.05° in rotation and 0.03 mm in translation [238]. Passive systems utilize retro-reflective markers that are placed on anatomical landmarks but require no power supply on the participant. This type of system has been found to be accurate to 63±5 μm [239]. Both systems suffer from the inability to track markers due to visual occlusion from other body parts. Both system types have high accuracy when measuring joint angles and segment position but are complex and not easily mobile [240–242].

Electromagnetic systems utilize body worn markers but rely on movement of these markers through a magnetic field rather than a visual field to track their motion. These systems can be accurate in their measurements to .25 mm [243–246] but suffer from a limited range based on the ability to generate a magnetic field in which the markers move [244,246]. Specific to cervical spine motions electromagnetic systems have high intraclass correlation coefficients for primary movements but these coefficients decrease in coupled movements [247].

Accelerometry based systems

The use of tri-axial accelerometers to measure motion has been gaining traction in recent history. Accelerometer data is calculated through extrapolating the velocities and time of movement to determine changes in space of the device [248,249]. These systems can track the movement of the device through 3 dimensions with moderate [250] to high accuracy [251]. These systems require a known start point and measurements of the length of the segments from which to extrapolate the data [252] which can be accomplished utilizing a number of set poses [253]. Accelerometer based motion capture give the user an option for 3-dimensional motion tracking when performing activities outside of a laboratory.

Head Accelerometry

The primary mechanisms of concussive injury are thought to involve linear and rotational head accelerations and velocities. The relationship between these variables and the symptoms of the injury are unknown. Translational acceleration caused by linear acceleration was first theorized to be the primary cause of concussive injury [56] but later studies reduced linear acceleration's contribution to 50% of the responsible forces during concussive blows [57]. Linear acceleration is believed to cause a pressure gradient resulting from a rapid deceleration, bringing about more focal injuries to the tissues. Rotational acceleration causes shear and tensile strain on the brain tissues [58,59] which have been shown to cause more diffuse injuries as well as injury to deep brain in areas where cortical injury is not present [60–62]. Currently, calculations such as the Head Injury Criterion (HIC) and Gadd Severity Index are used to attempt to identify the contributing factors in concussion risk as well as new measures to include the contribution of multiple factors[63]. Combined measures of linear and rotational acceleration have shown promise in increasing the predictive capabilities of head acceleration measurement [64]. The exact contribution of linear and rotational motion is currently not completely understood because of the variability in injury profiles and the frequency of concussions.

When studying sports related concussion, researchers have utilized two primary methods to understand the accelerations experienced during play. The first methodology attempted to recreate impact speeds and directions resulting in concussions during football play in a laboratory using headforms of Anthropomorphic Test Devices (ATD) based on video analysis of impacts [254]. The second method of quantifying the accelerations experienced during sport is to place measurement devices such as accelerometers and gyroscopes into the athlete’s helmet or directly on the athlete’s head. This technology allows potentially injurious accelerations to be quantified immediately during participation as well as collecting cumulative impact data from multiple players over the course of a season [26]. The ease of data collection utilizing the second methodology has allowed for the creation of large databases capable of identifying injurious acceleration profiles without the time requirement of lab recreation from video [256] yet there continues to be debate on the accuracy of these devices.

Currently there is a lack of strong support for any of the existing accelerometer based systems. A number of studies have been published utilizing the Head Impact Telemetry (HIT) system [23,24,257], yet there is an ongoing question regarding the applicability of these test results. This system is mounted inside of the helmet and the accelerometers used for measurement are pressed toward the head using foam standoffs. A study on the accuracy of the system has shown accuracy to within 0.9% in linear acceleration and 6.1% in rotational acceleration [258]. Testing in which the pressure between the helmet and the head form was controlled to match the 34th percentile of football helmet wearers and included absolute error and Root Mean Square Error (RMSE) calculations caused these numbers to become less accurate. In this research linear acceleration error was found to be 17.5% RMSE and rotational acceleration absolute error increased to 66.3% [259]. The results of this study as well as additional studies of the HIT system in hockey helmets [260] leaves questions as to the accuracy of the system for widely varying user interfaces as would occur in the full scale use of this product.

The X2 Biosystems' xPatch system is another option to directly measure accelerations of the head. This system consists of a three axis linear accelerometer and three axis gyroscope contained in a small appliance that attaches directly to the skin over the mastoid process of the athlete. The system allows measurement of head accelerations for activities whose participants do not typically wear headgear as well as improving construct validity of helmeted sport head accelerations by removing the head/helmet interface. The system is able to provide measurements of linear acceleration, rotational acceleration and rotational velocity. This device provides measurement of the accelerations of the head over a 100ms window at 1 kHz. The data system for the xPatch provides both a simple clinical interface for users as well as access to all data recorded by the device in both processed and raw forms. Previous research on the accuracy of a mouthguard based system indicated the design may be capable of accurately measuring the accelerations experienced by the head [261,262] yet limited research currently exists on the ability of the xPatch device to accurately measure head accelerations.

Research Program

The goal of this research is to develop effective mechanisms to implement form corrections in youth football tackling and understand the effectiveness of a recommended tackling form in reducing head accelerations in youth athletes. In order to achieve these goals research will be undertaken to: 1) develop a valid and reliable mechanism to provide verbal feedback to athlete’s regarding their tackling form, 2) determine the effectiveness of different models to improve tackling form when providing video feedback to youth athletes and 3) determine the ability of training in a recommended form to decrease the head accelerations experienced by tacklers.

Chapter 3: Inter-rater Agreement of a Tackling Performance Assessment Scale in Youth American Football

Introduction

A 2015 position statement by the American Academy of Pediatrics recommended "Officials and coaches must enforce the rules of proper tackling, including zero tolerance for illegal, head-first hits'[8]. During the 2015 high school football season, seven high school football athletes' deaths were directly attributable to head and spine injury[12]. A recommendation has been made by USAFootball, a major youth football regulatory body, regarding mechanisms to reduce contact of the players head during tackling. The Heads Up tackling style recommended by USAFootball provides a framework, including progressive drills, to instruct the recommended tackling technique, as a mechanism to provide feedback to the learners of this style has yet to be developed. Verbal feedback is the standard mechanism utilized to improve movement technique in athletes of all ages and sports. The ability to provide consistent and valid feedback is crucial to the success of any coaching intervention. Identifying the critical components of the USAFootball Heads Up tackling style as perceived by the stake holders within the USAFootball organization and leagues which implement this style as well as identify the level of agreement between raters providing verbal feedback to the learners is of critical importance.

The USAFootball tackling framework contains six phases designed to aid in performance of a safe tackle. This framework focuses both the coach and the player to the specific needs of the athlete at their individual phase of learning the technique. The recommended phases are:

1. Head placement across the front of the target.
2. Achieve contact in the appropriate strike zone.
3. Make contact with the shoulder rather than the head.
4. Develop and maintain strong fundamental skills.
5. Advance the technique from static to dynamic movements through appropriate drilling.
6. Progress the drills from static to dynamic situations to mimic game situations while maintaining safety.

These six critical components are emphasized to improve the chances of bringing the target to the ground during competition, but a limiting factor is whether they actually aid in reducing contact to the head of the tackler.

Recent research has been completed regarding the effectiveness of the USAFootball comprehensive coaches' instruction and practice requirements in reducing head accelerations and injury rates in youth football athletes. Heads Up Football (HUF) league coaches receive hands on training regarding proper equipment fitting, didactic and participant demonstration of proper tackling technique and instruction in drills that reduce head contact[27]. Participants in HUF leagues experienced less head impacts during practice registering both 10 and 20g's when compared to non-HUF leagues[27]. The HUF leagues also saw a decrease in practice injury rates when compared to non-HUF leagues[28]. Utilization of HUF practice recommendations shows the ability to decrease injury risk in youth athletes, though the effect of the tackling technique may not be the primary driver or may not translate to game performance.

Visual estimation of poses and activity while common in both performance and feedback should be utilized with caution and an understanding of the variability of the measures. While visual estimation of movement patterns is standard practice in coaching[218], the use of additional measurement techniques has increased [219–221,263]. Visual estimation of joint motion has been reported to be highly variable and with limitations in its accuracy[223–226]. Despite these concerns visual estimation of movement requires no equipment and can be performed immediately without data processing. This makes visual estimation of movement a commonly utilized mechanism in movement instruction. Utilization of rater training and standardized procedures has been shown to improve rater agreement in dynamic movements[227–229]. Providing consistent feedback to learners is important to develop the skill being learned. When developing motor strategies, learners are better able to attain a higher level of performance when the model or feedback they receive is consistent[264–268]. Combined feedback from visual estimation and other sources are common in feedback mechanisms and with training can be reliable. The purpose of this study was to identify the inter-rater agreement and validity of a six criteria tackling scale utilizing video review. Identification of the rater’s ability to provide both consistent and accurate feedback is important in developing training tools to improve tackling form. The development of this tool will give sport and movement coaches the ability to provide appropriate feedback both in a verbal only mechanism as well as in combination with other modalities.

Methods

The Qualitative Youth Tackling Scale (QYTS) was developed through analysis of the recommended USA Football Heads Up tackling style. Researchers worked with the USAFootball committee who developed the Heads Up tackling standard to identify a minimal set of identifiable movements that would achieve the goals of the program. Components of the skill identified by the authors and the USA Football Heads Up developers deemed to be critical to the safety considerations of the style were assembled into the QYTS. The QYTS consists of:

1. Maintain body control with short steps below 75% of standing pelvis height.
2. Extend the shoulder to beyond 45 degrees then completed an anterior motion during the tackle.
3. Lower the body center of mass to 75% of standing pelvic height by bending at the knees.
4. Keep the head to the far side of the target and do not allow it to make contact with the target.
5. Contact the target with the front of the shoulder by maintaining the trunk between 35 and 55 degrees relative to the ground to keep.

6. Keep the neck in greater than 45 degrees extension in order to see the target and avoid contact with the crown of the head.

Inter-rater agreement was considered utilizing two Certified Athletic Trainers (ATC) with six and ten years of post certification experience, respectively, and two novice raters with no formal training in movement evaluation. These participants were provided with training on the components of the Qualitative Youth Tackling Scale (QYTS). The rater training included an explanation of the correct tackling form, examples of expert tackling and an immediate feedback pre-test utilizing examples of youth athletes performing both correct and errored tackling. Each rater reported their evaluation of the performance as correct or incorrect as it pertained to the guidelines for each movement item. Participants were required to achieve 80% accuracy on the pre-test prior to rating experimental trials. The total time spent on the training prior to rating the experimental videos was recorded to determine training exposure. Participants were then given 20 trial examples to rate independently. The raters were able to review the video as many times as needed and were given full control over the playback of each video. The total time to complete the rating was recorded. Overall rater agreement was calculated utilizing a Fleiss' Kappa score. Rater agreements within the ATCs, Novices and between ATC and Novices were calculated utilizing individual Cohen's Kappa scores and positive (PA) and negative agreement (NA). In order to understand the relationship between the raters' evaluation of the performance and the movement being performed, agreement between the raters' scores and a validation standard were performed utilizing a dichotomous split of the motion capture data, within or outside of the desired range of motion of the movement goal, to calculate averaged Cohen's Kappa scores, PA and NA. Because accurate visual estimation is inherently difficult, the validation measure was then dichotomized in increasing bands of five percent accuracy from 100% to 80%. This expanding band allowed for an increasing laxity in the validation measure to determine if raters were close to the correct estimate of movement. Averaged Cohen's Kappa scores, PA and NA were then calculated for each point to determine if an expanded definition of accuracy increased rater agreement.

Results

Fliess' Kappa measures between all raters were found to be moderate for head placement (*k*=.48), moderate for cervical extension (*k*=.38), trunk inclination (*k*=.37), shoulder extension (*k*=.27) and step length (*k*=.29), and no agreement for pelvic height (*k*=.-16) (Table 1). Cohen's Kappa measures between ATC's found substantial agreement between ratings of cervical extension (*k*=.69), head placement (*k*=.61), pelvic height (*k*=.73) and shoulder extension (*k*=.70). Step length results indicate moderate agreement (*k*=.49) and trunk inclination results indicate fair agreement (*k*=.24) (Table 2). Cohen's Kappa measures between Novice Raters found moderate agreement for head placement (*k*=.41). Step length (*k*=.34), trunk inclination (*k*=.40), and shoulder extension (*k*=.34) were found to have fair agreement. Slight agreement was found for cervical extension (*k*=.15) and pelvic height (*k*=.11) (Table 3).

When compared to the dichotomized validation measures of each of the six components provided by the motion capture system the ATC rater's average Cohen's Kappa agreement was substantial for pelvic height (*k*=.68), moderate for step length (*k*=.44) and cervical extension (*k*=.55) and fair for trunk inclination (*k*=.31) and shoulder extension (*k*=.27) (Table 4). The novice raters had a lower level agreement; moderate for pelvic height (*k*=.57), fair for cervical extension (*k*=.25), trunk inclination (*k*=.39), and step length (*k*=.24) and slight for shoulder extension (*k*=.05) (Table 5).

Banded averaged Cohen's Kappa measures between raters and the motion capture found measures of trunk inclination (*k*=.35-.50) and shoulder extension improved (*k*=.16-.55) with lower percentages of the desired movement while the Kappa reported from pelvic height (*k*=.62-.00) comparisons decreased (Figure 5). Banded positive agreement increased between 100% and 90% for step length (51% to 57%) and trunk inclination (50% to 65%), while shoulder extension continued to improve (35% to 78%) through 80% of the validity measure (Figure 6). Banded negative agreement remained stable for all measures with the exception of pelvic height which decreased from 86% agreement at 100% of the validity measure to 75% at 90% then sharply to 0% at 80% of the validity measure (Figure 7). Average time to complete the training was 34±8 minutes. Average time to complete the rating of the 20 videos was 20.5±3 minutes.

Table 1. Fleiss Kappa Measures between all raters

	Cervical extension	Trunk Inclination	Head placement	Pelvic height	Shoulder extension	Step length
Fleiss' Kappa	0.38	0.37	0.48	-0.16	0.27	0.29
Lower Bound	0.20	0.19	0.30	-0.34	0.09	0.11
Upper Bound	0.55	0.54	0.66	0.02	0.45	0.47

Table 2. Cohen's Kappa, Positive and Negative Agreement percentage between AT raters

	Cervical extension	Trunk Inclination	Head placement	Pelvic height	Shoulder extension	Step length
Cohen’s Kappa	0.69	0.24	0.61	0.73	0.70	0.49
Positive Agreement	87%	40%	94%	80%	84%	60%
Negative Agreement	82%	80%	67%	93%	86%	87%

Table 3. Cohen's Kappa Positive and Negative Agreement percentage between Novice Raters

	Cervical extension	Trunk Inclination	Head placement	Pelvic height	Shoulder extension	Step length
Cohen’s Kappa	0.15	0.40	0.41	0.11	0.34	0.34
Positive Agreement	64%	57%	88%	57%	52%	77%
Negative Agreement	40%	77%	50%	53%	35%	57%

Table 4. Cohen's Kappa Positive and Negative Agreement percentage between rater and validation measure for AT raters

			Cervical extension	Trunk Inclination	Pelvic height	Shoulder extension	Step length
AT	Cohen's Kappa	Rater 1	0.50	0.15	0.74	0.30	0.39
		Rater 2	0.60	0.48	0.63	0.24	0.48
		Average	0.55	0.31	0.68	0.27	0.44
	Positive Agreement	Rater 1	76%	36%	80%	46%	55%
		Rater 2	82%	57%	73%	40%	57%
		Average	79%	47%	76%	43%	56%
	Negative Agreement	Rater 1	74%	76%	93%	74%	83%
		Rater 2	78%	91%	90%	80%	91%
		Average	76%	83%	91%	77%	87%

Table 5. Cohen's Kappa Positive and Negative Agreement percentage between rater and validation measure for Novice raters

			Cervical extension	Trunk Inclination	Pelvic height	Shoulder extension	Step length
Novice	Cohen's Kappa	Rater 1	0.30	0.38	0.44	0.01	0.24
		Rater 2	0.20	0.40	0.69	0.10	0.24
		Average	0.25	0.39	0.57	0.05	0.24
	Positive Agreement	Rater 1	63%	50%	67%	25%	47%
		Rater 2	69%	57%	80%	31%	47%
		Average	66%	54%	73%	28%	47%
	Negative Agreement	Rater 1	67%	88%	73%	50%	61%
		Rater 2	43%	77%	88%	67%	61%
		Average	55%	82%	80%	58%	61%

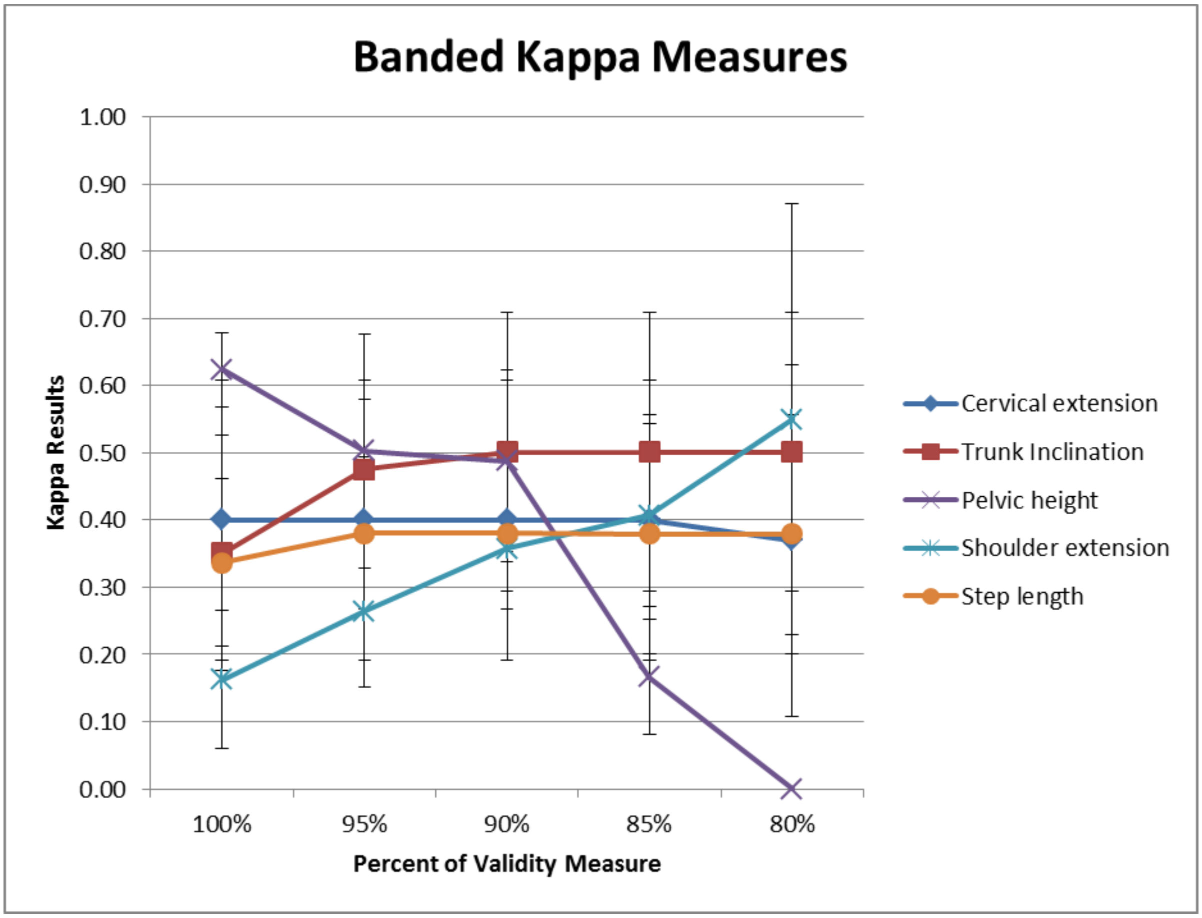


Figure 5. Banded Average Cohen's Kappa Measures between all raters, banded from 100% of desired movement to 80% of desired movement

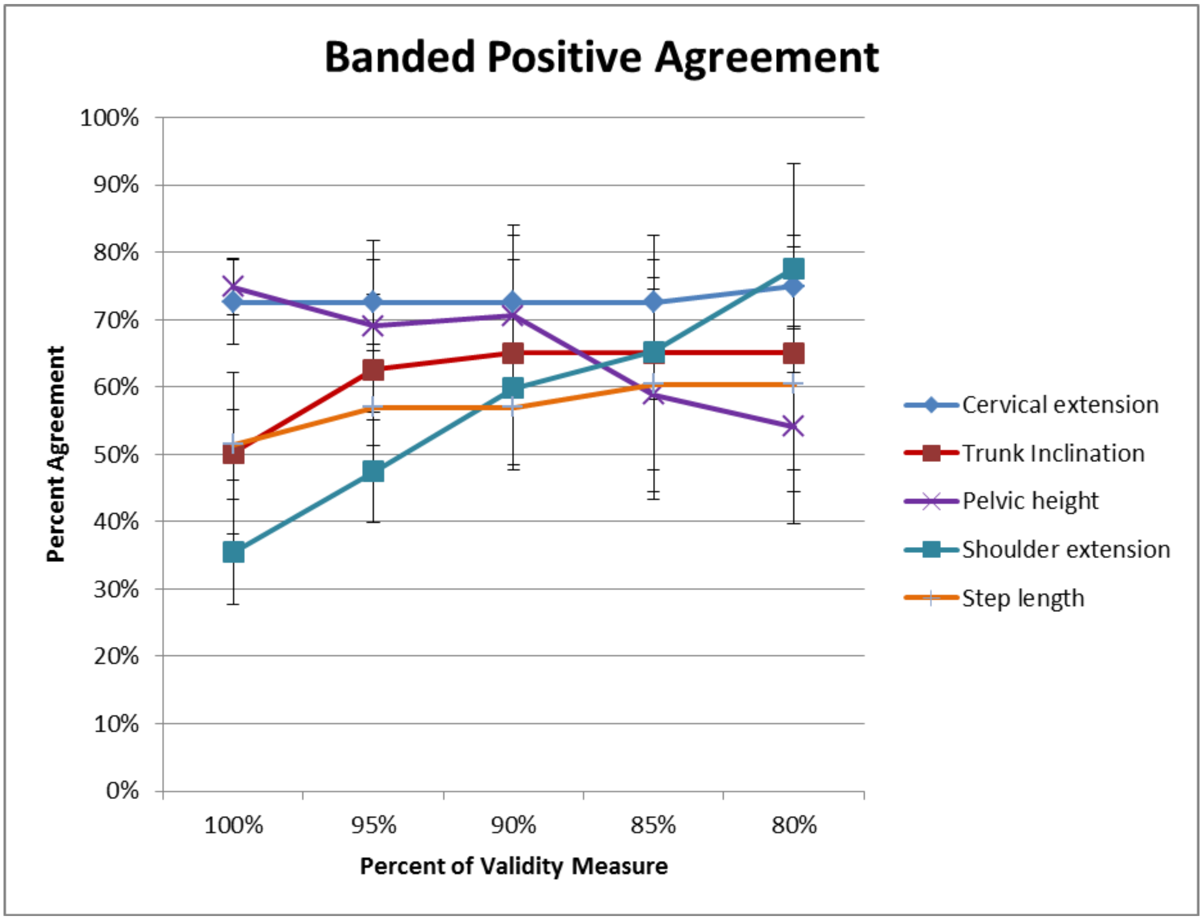


Figure 6. Banded Average Positive Agreement Measures between all raters.

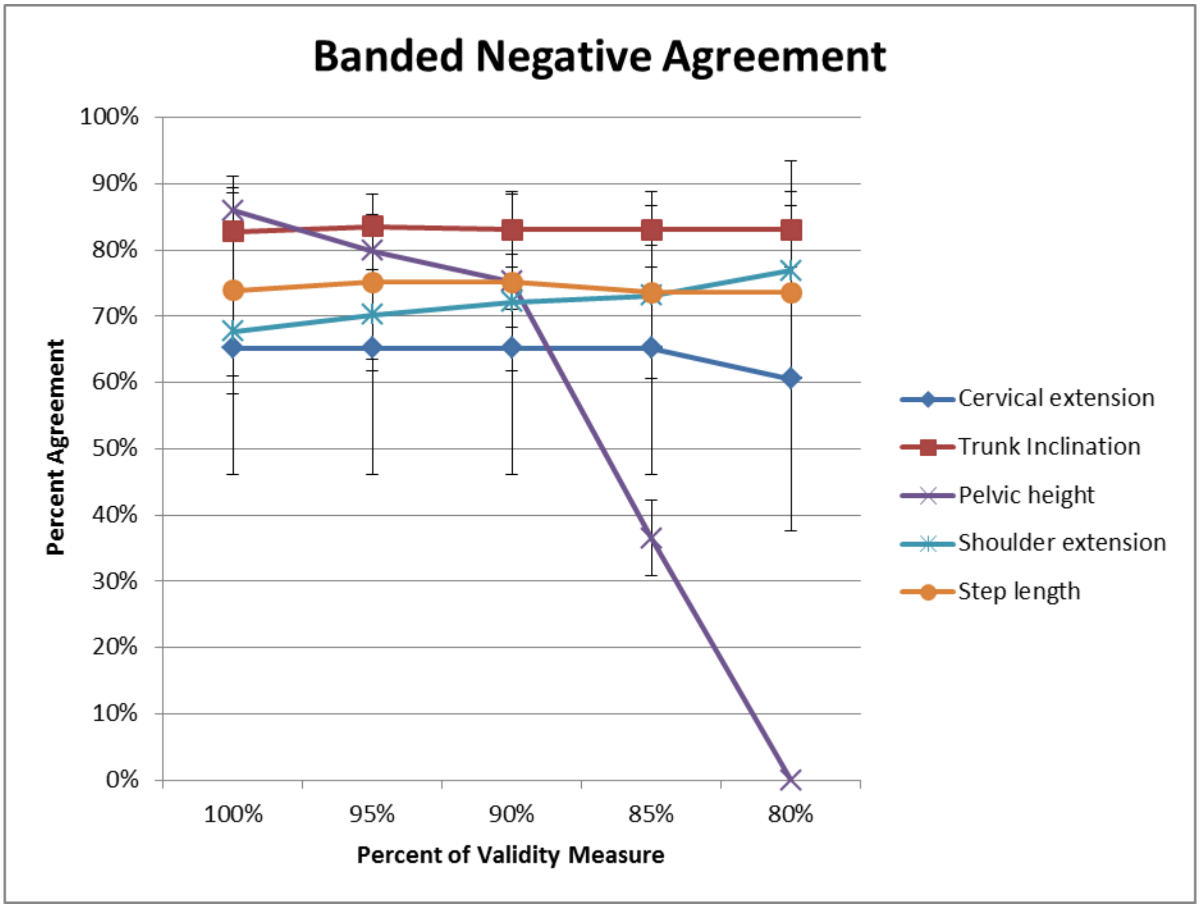


Figure 7. Banded Average Negative Measures between all raters

Discussion

Raters of the QYTS are able to successfully identify the movements performed during a tackle, but rating should be limited to those with experience visually identifying movement patterns. The results of this study indicate substantial to slight agreement between raters of the QYTS dependent on the movement and the rater's background. Athletic Trainers had higher levels of agreement than non-certified novices through most movements as well as a higher level of agreement with the validation measurements when compared to the novice raters. Banded Kappa analysis indicated the agreement between raters improved when accepting a lower percentage of accuracy compared to the motion capture system for measures of shoulder extension and trunk inclination yet agreement measures decreased at lower measures of accuracy for pelvic height.

Overall agreement measures between raters found fair agreement between all raters. When rating cervical extension, trunk inclination, head placement, shoulder extension and step length the raters were able to achieve Fleiss' Kappa ratings within the fair range. While agreement may be low in these results, the outcomes are comparable to other studies of visual estimation [224,226,227,269] and better than others[270]. Visual estimation of movement is often hampered by difficulty judging the movements produced. This result is seen across many areas of study, such as knee motion during running [223] and cervical spine motion[226]. In the case of the QYTS, the raters were able to utilize video playback to improve their evaluation of the movement, though this method may be offset by the quality of the image and number of variables to be evaluated[263]. The pre-assessment training for the raters may have not been adequate to allow for a thorough understanding of the method of movement evaluation[271]. The need for evaluating the training program for raters should be evaluated, though such additional training maybe ineffective[223]. All of these variables may have played a part in the less than perfect agreement seen in the comparison between all raters.

Athletic Trainers are experienced in evaluating human movement and because of this were able to achieve both higher agreement between raters and between raters and the validity measures[227]. In the training to become ATC's, the raters would have been exposed to many cases of evaluating movement visually. This may have allowed the raters to gain a perspective or evaluation technique to improve their accuracy and reliability when viewing human movement. Athletic trainers also have a better understanding of the visual appearance of the range motion referenced in the training, having had experience measuring and evaluating movement. They are better able to understand the reference to 45 degrees of shoulder extension during QYTS training, having measured such movements themselves as part of their training. The increased agreement seen in both the inter-rater comparison and between experienced raters and validity measures may be a function of the additional training and experience of the ATC raters.

When the percentage of accuracy required by the validity rating is reduced, the validity agreement for trunk inclination and shoulder extension improved while pelvic height agreement decreased. The accuracy required by the validity agreement measures was banded from 100% accuracy to 80% accuracy by 5% increments. As the accuracy required was reduced, shoulder extension agreement improved across all bands. While it appears that raters had difficulty identifying movements over 45 degrees, they were able to separate those who extended the shoulder to at least 80% of the desired movement profile. Further investigation reveals raters consistently responded affirmatively down to 50% of the desired rating, or 25 degrees shoulder extension. Rating of trunk inclination improved with a shift to 95% accuracy at which time the improvement in agreement stabilized. Raters reached their highest consistency in agreement when the movement was considered correct between 43 and 57 degrees trunk angle. These expanded movement parameters may be satisfactory for proper execution of the tackle, though this answer is beyond the scope of this project.

Pelvic height grading suffered from expanding the validity measure, as those trials that were correctly identified at 100% of the validity measure become incorrect when compared to the expanded validity measure. Raters for this measure were able to identify the movement correctly at its desired height and their measures would suffer if additional error was allowed to be considered appropriate. This indicates they were able to accurately determine the percentage of standing pelvic height. These results had the highest average agreement when maintaining the standard as instructed. These results indicate the highest validity agreement measures were achieved when the accuracy of the validity measure was placed at 100% for pelvic height, 80% for shoulder extension and 95% for trunk inclination. Overall the best percentage of accuracy measures is 90%.

Limitations to this research include a small sample of raters with limited training on the QYTS. Future studies should investigate a larger cohort of raters, both experienced and inexperienced in a more in-depth training program. Special consideration should be placed on including coaches at both the youth and high school levels. Coaches, trainers and Athletic Trainers often provide verbal feedback to players without the aid of video, thusly additional research should examine the ability of the QYTS to be utilized in real time. Additional research should also examine the intra-rater reliability of the QYTS scale over time.

Raters of the QYTS display a range of agreement from substantial to slight throughout each of the six components. More experienced and movement trained raters showed a higher level of agreement both with each other and with a validation standard. The validity agreement measures improved for shoulder extension and trunk inclination with a downward adjustment to the accuracy tolerances while the agreement of measures of step length decreased with this adjustment.

Chapter 4: Effect of Video Feedback Model Type on Performance Improvement in Youth Athletes Performing an American Football Tackle

Introduction

A 2015 position statement by the American Academy of Pediatrics recommended, “Officials and coaches must enforce the rules of proper tackling, including zero tolerance for illegal, head-first hits’[8]. In 2015,eight high school football athletes’ death were directly related the head and spine injury[9]. Reports estimate 1.6 to 3.8 million cases of concussion occur in sports and recreation each year in the US, with sports related concussion rate estimates between 0.19 and 1.78 per 100,000 participants[10,11]. Despite continued efforts by numerous organizations, the incidence of concussion continues to increase[12]. Head contact during blocking and tackling are the most prevalent mechanism of injury or activity associated with football related concussions [13]. Instruction of proper football tackling technique has been proposed as a method to aid in the reduction of football related concussions.

Video feedback is a common motor learning technique that has been used in many situations to instruct and alter movement patterns to aid in mitigating injuries and improve athletic performance[3–7]. The model utilized by the video feedback technique can have an effect on the information the learner receives from feedback[14,15], to date the effect of feedback model type in football tackling has not been described.

Recent research indicates providing coaches with a comprehensive education plan consisting of tackling training, equipment fitting and practice guidelines may reduce the number of head impacts experienced by youth football players. A recommendation has been made by USAFootball, a major youth football regulatory body, regarding guidelines to reduce contact to the player's head. The Heads Up program recommended by USAFootball provides a framework, consisting of progression of drills, to instruct the tackling technique. Despite this a standardized mechanism to provide feedback to the learners of this style has yet to be developed. Designed in conjunction with USAFootball the Qualitative Youth Tackling Scale (QYTS) provides a feedback framework containing six components of a safe and effective vertical tackling style[27]. These six items focus the learner on portions of the archetypal form tackle that primarily remove the head from contact with a secondary goal of a successful tackle of the opponent.

Video feedback may provide an effective means to integrate feedback into youth performance training. Video feedback has been used by coaches, trainers or medical professionals to help alter the motions of athletes [6,162,198], in the rehabilitation setting [199–203] or in human performance [204,205]. The model type utilized can alter the effectiveness of the feedback being provided. When providing video feedback, the instructor must be aware of the effect of the model used to exhibit the proper execution of the skill. The model provides a visual blueprint for the learner to mimic as well as to draw inferences, either explicit or implicit, regarding the proper movement pattern. Several investigations have been conducted utilizing augmented video feedback to improve movement patterns in adolescents with varying models [14,208–212]. The use of Self-Observation during video feedback involves providing the learner with a video playback of their current performance of the skill [14,15,210]. This type of feedback provides no visual information on the desired pattern and thus requires all information on this pattern to be provided through another mechanism. Expert only video feedback involves providing the learner with video of an expert's performance only. This video type allows the learner to see the form they have been instructed to perform, but provides no information regarding current performance[213–217]. Expert only feedback is often referred to as modeling, as the expert provides the learner with a model to be imitated. Self-observation plus expert model feedback provides the learner with information on their current performance plus information on the correct performance of the skill[162,208]. This method allows the learner to identify the differences between their current performance and the expert model. All of these models provided during video feedback have been indicated to be capable of altering movement patterns.

The purpose of this research project is to understand the effect of video feedback models on movement performance in youth football athletes. The effect of model type on changes in performance of a specified tackling form has not been studied in youth athletes. We theorize that providing self-observation plus expert model feedback will allow greater improvement in the performance of the instructed tackling form. Of the four model types presented, self-observation plus expert model provides the learner with an image of their current performance and the goal performance, which is theorized in this study to provide superior changes in performance when compared to the other models in this study.

The Qualitative Youth Tackling Scale

1. **Maintain the neck in an extended position prior to contact, not striking the opponent with the crown of the helmet**
2. **Contact the target with the front of the shoulder**
3. **Lower the body center of mass by bending at the knees**
4. **Keep the head to the far side of the target and not allow it to make contact with the target**
5. **Utilize the arms in a posterior to anterior motion during the tackle**
6. **Maintain body control with short steps on approach to the target**

Figure 8. The Qualitative Youth Tackling Scale

Methods

Participants were quasi-randomly assigned to one of four groups to maintain even group numbers. Training and testing took place over a one-day period. Prior to group assignment demographic data were collected including: age, height, weight, sex, school level, seasons playing tackle football. The training included baseline testing and four training blocks of three tackles in the motion capture volume.

Tackling Circuit

The tackling circuit consisted of tackles in which the learner and the target are offset one foot at a distance of five feet (Figure 9). The target for this testing was a 90 pound stand up tackling dummy with the center of mass near the contact area which was specifically designed for this research (Appendix A). At the baseline time point, the participant was instructed to tackle the dummy as they typically do when playing football. Participants were then given instruction on the six standard components of the USAFootball tackling style which are contained in the QYTS, after which they performed three tackles. These tackles were then used to provide the first feedback intervention. The feedback conditions were:

Self-Feedback Group: The Self-Feedback Group received video and verbal feedback regarding their tackling performance using only the participant as a model in the video feedback. Verbal feedback was standardized based on errors.

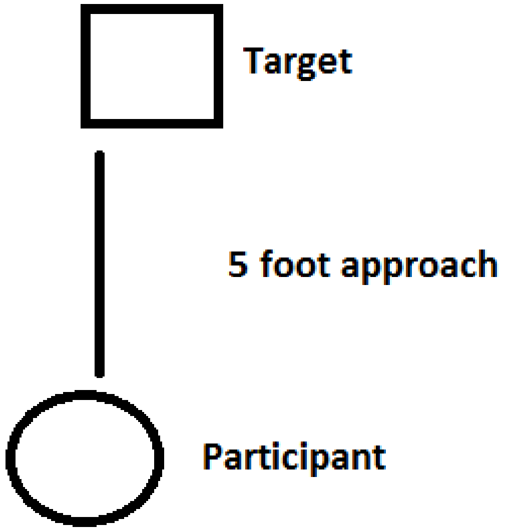


Figure 9. Participants starting position relative to target.

Expert Feedback Group: The Expert Feedback Group received video and verbal feedback regarding their tackling performance using only video of an expert as a model in the video feedback. The expert model performance was measured at: cervical extension 55º, trunk angle 50 º, correct head placement, shoulder extension 55º , pelvic height 65%, and step length 60% of standing pelvic height. Verbal feedback used the same standardized format as all other groups.

Combination Feedback Group: The Combination Feedback Group received video and verbal feedback regarding their tackling performance using both the participant and an expert as model. Verbal feedback used the same standardized format as each of the other groups. Videos of the participant and the expert were temporally aligned utilizing the feedback software

Verbal only Group: The verbal only group did not receive any video feedback but received verbal feedback in the same standardized format as all other groups.

Feedback Process

Feedback was provided in four blocks of three trials. The participants were asked to identify the portions of the tackling movement that they performed correctly. Verbal feedback was provided by the researcher based on the errors assessed according to the requirements of the QYTS once the participant had finished grading their performance. Previous research has indicated expert visual raters are capable of achieving substantial to fair agreement with an objective measure of movement when providing feedback on the QYTS (Figure 2). The verbal feedback elements of the QYTS are placed in order of importance to participant safety as determined by an expert panel. The top two errors based on player safety from QYTS were provided verbally to the participant (Appendix B). Participants were given access to a 17x10 inch computer screen for viewing of all feedback videos. The video in presented to the participant for feedback at the end of each block was selected by identifying the trial video in which the participant made the highest number of errors from the QYTS. They were then instructed to view the video format specific to their treatment condition (Self, Expert, Self plus Expert or Control) four times. The combination feedback group was presented with a split screen view of each portion of the feedback; all others were given a full screen (Appendix E). The video presented in the feedback groups that utilize a video of the participant was updated after each block to present the videos of trials performed during the previous practice block. The number of repetitions of feedback was the same for all participants receiving video feedback. The playback of the video was controlled by the researcher. Verbal feedback only subjects were given verbal feedback regarding which errors were present but then watched an assembled video of football pass plays without tackles for the same time period as the treatment groups to standardize the amount of time provided between trial sessions across all groups. The amount of feedback provided to each participant in each movement item was recorded.

Data Analysis

Measurement of movement was performed utilizing a 10 camera Vicon motion capture system. 2-Dimensional video data were collected with a Microsoft Surface tablet. This video was utilized to provide video feedback to the participant. Step length and Pelvic height data were normalized to standing pelvic height to control for participant height differences. Statistical analyses consisted of separate 4 (feedback group) x 3 (block) ANOVA of kinematic measures for each biomechanical variable of the QYTS by time point (Pretest, Instruction and Final). The average range of motion for each time point provided one data point for each participant over the five motions analyzed utilizing motion capture. By maintaining balance within the groups, the effect of non-normality and non-sphericity on statistical analysis are minimized[272]. The number of trials in which participants correctly perform the head across the front criteria was assessed pre and posttreatment and the total number of correct responses at each time point was analyzed utilizing a Kruskal–Wallis one-way analysis of variance with post hoc Wilcoxon Signed Ranks tests to identify individual relationships. Statistical significance values were set to an *a priori* significance of $p \leq 0.05$.

Results

Thirty two participants were recruited (28 male, 4 female) and equally divided between all conditions for a total of 7 males and 1 female per group. Participants averaged 11.8 ± 0.8 years of age with 2.5 ± 2 years of experience. Amount of feedback for each movement item is reported in Table 6. Significant effects of treatment were found for shoulder extension, cervical extension, pelvis height and step length over time but no significant interactions were noted. Analysis of the effect of treatment on shoulder extension found a significant improvement toward the instructed movement over time (p=0.036, F=3.515, $\eta_p^2 = 0.112$, power=.632), but no group by time interaction (p=0.910, F=0.329, $\eta_p^2 = 0.034$, power=.133, Figure 10). For cervical extension there was a significant improvement between time points (p=0.009, F=5.078, $\eta_p^2 = 0.154$, power=.799) but no group by time interaction (p=0.473, F=0.942, $\eta_p^2 = 0.092$, power=.341 Figure 11). A significant positive effect of treatment was found over time for pelvis height (p<0.001, F=8.817, $\eta_p^2 = 0.239$, power=.964) but no group by time interaction (p=0.132, F=1.725, $\eta_p^2 = 0.156$, power=.605, Figure 12). There was a significant shortening of step length due to treatment (p<0.001, F=15.517, $\eta_p^2 = 0.357$, power=.999) with no group by time interaction (p=0.458, F=.964, $\eta_p^2 = 0.094$, power=.349, Figure 13). There were no significant effects of treatment for trunk angle (Time: p=0.372, F=1.222, $\eta_p^2 = 0.041$, power=.254 Group by time interaction: p=0.605, F=0.797, $\eta_p^2 = 0.079$, power=.289, Figure 14). Kruskal Wallis tests revealed no significant differences in number of correct head placements between the groups at baseline (p=0.654), instruction (p=0.497), or post treatment (p=0.336).

Table 6. Total feedback amount for each feedback item per group

	Shoulder Extension	Cervical Extension	Trunk Position	Pelvis Height	Step Length	Head Placement	Total
Self Model	4	5	6	20	20	3	58
Expert Model	2	3	11	15	7	5	43
Self plus Expert Model	11	5	11	18	12	0	57
Verbal Only	5	5	8	17	10	0	45
Total	22	18	36	70	49	8	

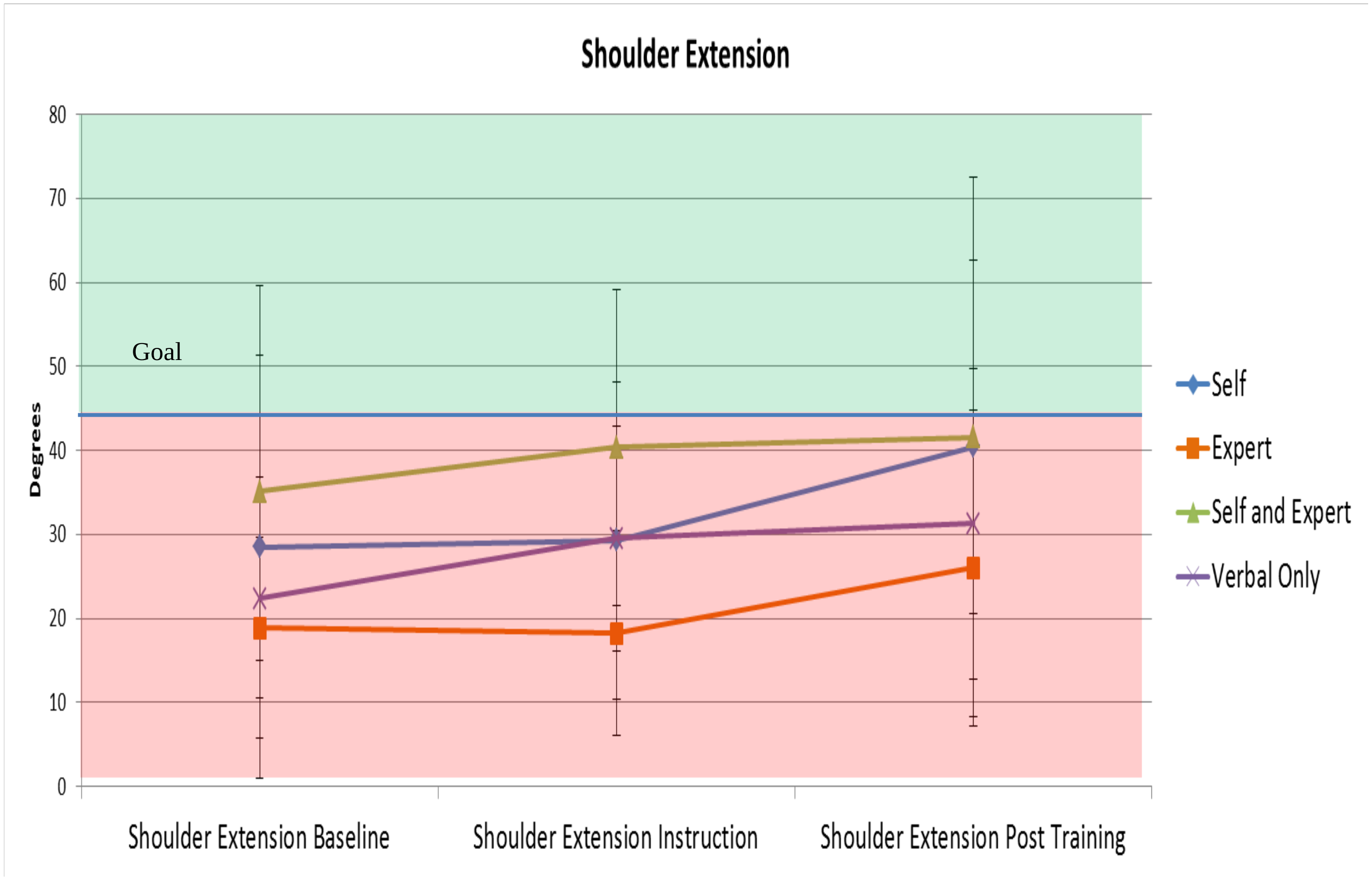


Figure 10. Effect of Treatment on Shoulder Extension at Baseline, Instruction and Post-training time points.

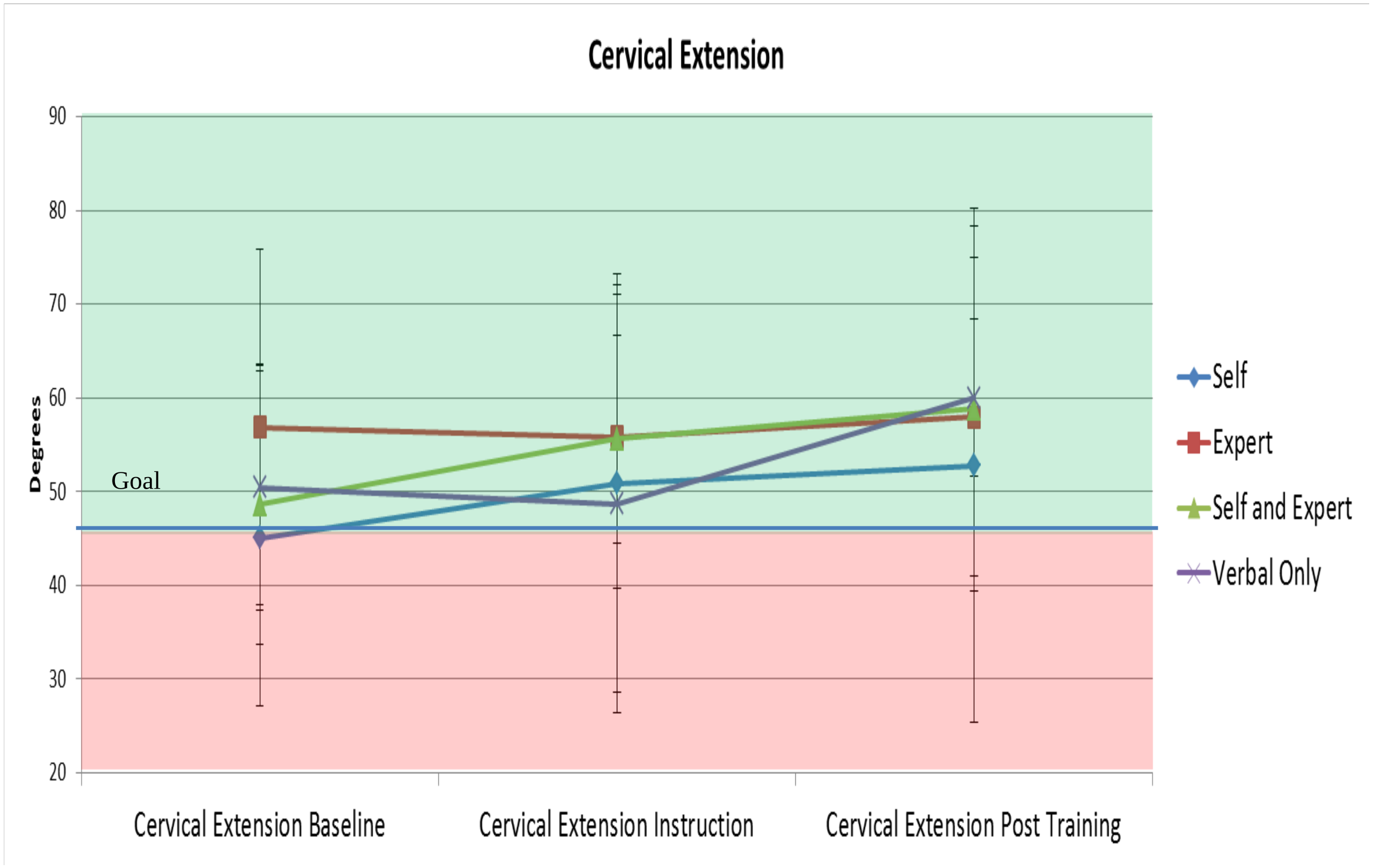


Figure 11. Effect of Treatment on Cervical Extension at Baseline, Instruction and Post-training time points.

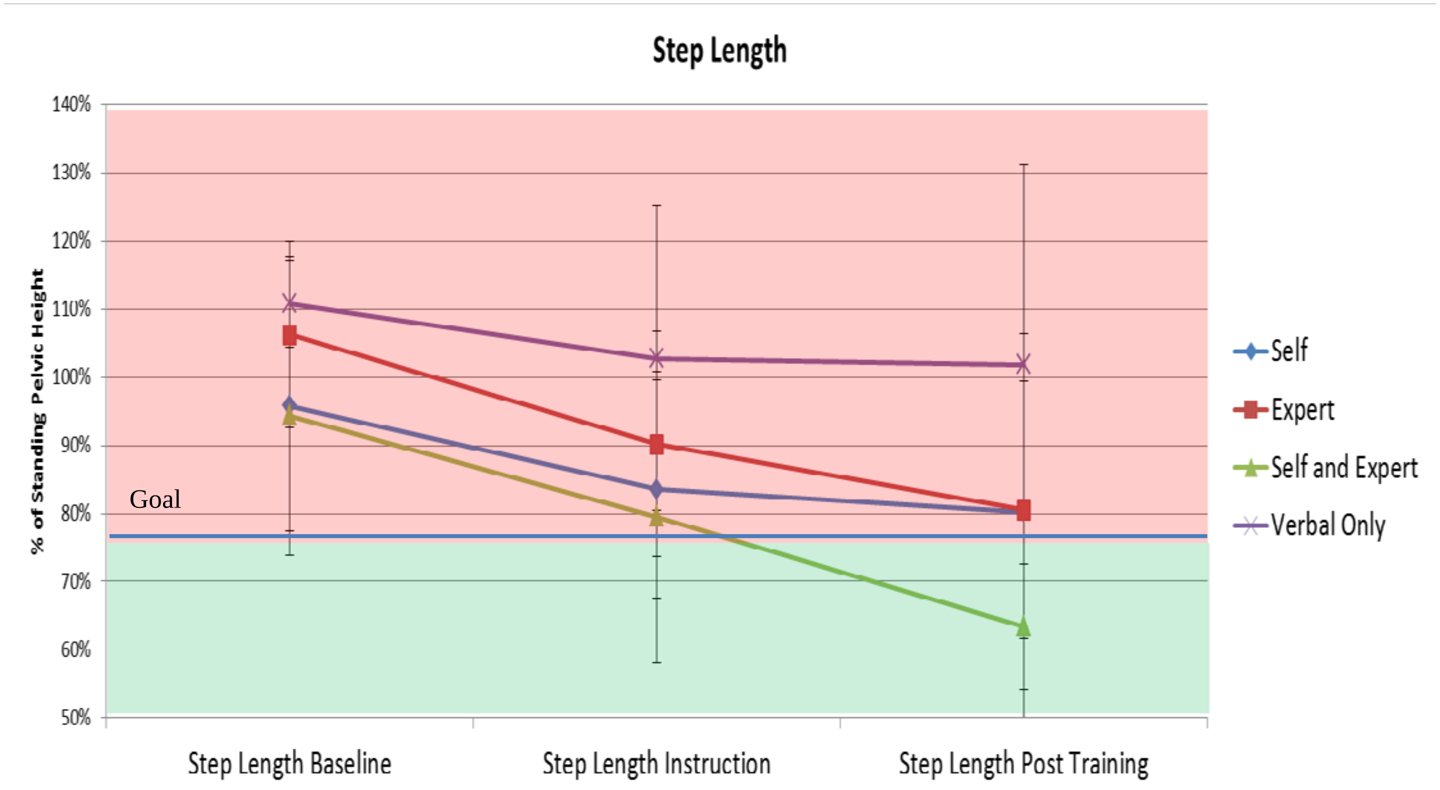


Figure 12. Effect of Treatment on Step Length at Baseline, Instruction and Post-Training time points.

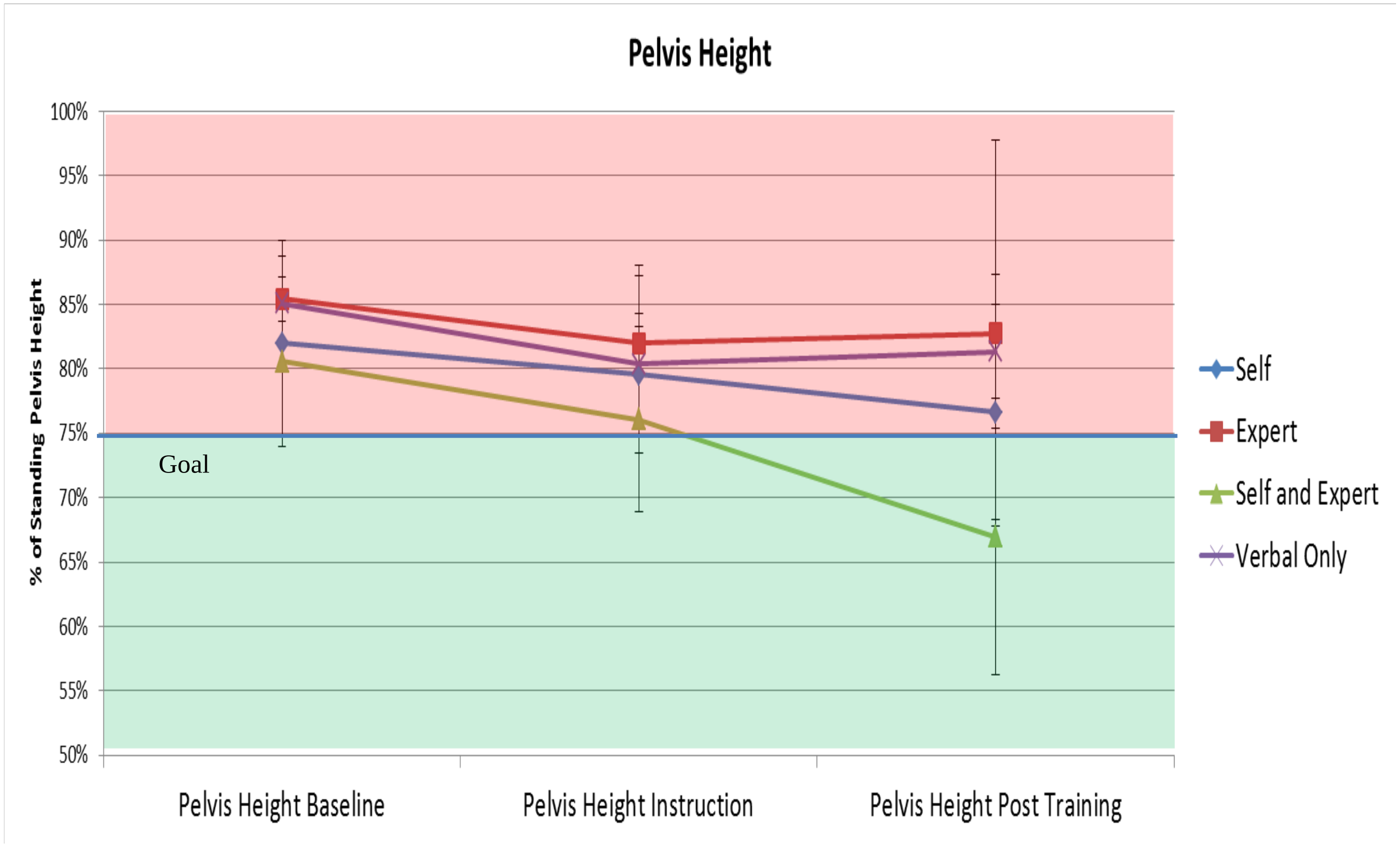


Figure 13. Effect of Treatment on Pelvis Height at Baseline, Instruction and Post-Training time points.

Figure 14. Effect of Treatment on Trunk Angle at Baseline, Instruction and Post-training time points.

Discussion

The results of this study indicate a combination of video and verbal feedback is effective in improving some aspects of a heads up vertical tackle style, yet the effects of the treatment may be driven by the verbal feedback portion. The verbal feedback presented to the participants provided enough information to allow them to alter their form. Differences between the groups were also difficult to detect due to smaller than expected effect sizes of each of the treatments. The results do not show a significant difference in the effect of the model type used during video feedback on tackling performance in youth participants.

All groups improved on some aspects of the instructed motion, but no model type provided video feedback that was significantly superior to the others. The verbal group's improvement along with the video feedback groups indicate it is plausible that the primary influence of this change was the verbal feedback provided. Verbal feedback is a simple and readily accessible mechanism to provide feedback[273]. Accurate and reliable feedback is a key to any feedback mechanism[274–276]; assessment and feedback of movement is challenging and is best provided by those with experience judging movement[227].

The effect of verbal feedback overshadowing video feedback varies from the current literature though the verbal feedback procedure was more in-depth than most control verbal feedback conditions. Many verbal feedback control conditions lack a reflective component[211] or control comparisons lack feedback of any kind[6,210]. The verbal feedback mechanism utilized required the participant to focus on their movement by recalling which parts of the tackling form they correctly performed. This action required the participant to recall their activity and focus on their own movement. After identifying their own movement they were given feedback regarding the quality of their movement from an observer. This activity both maintained the attention of young learners but also required them to reprocess the movement activity they had just performed. This mechanism has been effectively utilized in the development of gymnastic and technical music skills [277,278] to the same result. The verbal feedback and the reflection methodology utilized within it possibly provided enough information to the learner, such that the video feedback may have been extraneous.

Shoulder extension results indicate an increase in the peak extension achieved post training. All participant groups' baseline scores are below the movement pattern minimum of 45 degrees. With training all groups' scores increased toward the minimum score near uniformly. The impetus for increasing shoulder extension is to prime the arm to perform rapid forward motion on contact with the opponent in order to utilize the arms to facilitate a successful tackle[16]. Adolescents may be capable of understanding the verbal feedback for this movement, making the video feedback redundant[279]. While no groups significantly improved over the other, the improvement of all groups indicates providing verbal feedback may be sufficient to improve shoulder extension performance.

Cervical extension training resulted in significant improvement in all groups with no effect of the individual groups. All groups began training at or above the 45 degree minimum for cervical extension. This would have limited the verbal feedback provided during training due to proper performance. Maintaining cervical extension has been a part of instructed tackling technique since the outlawing of spearing in the 1970's[45,49] and thus the importance of maintaining an extended cervical position is known across all levels of previous instruction.

Trunk angle during tackling did not significantly change between groups or over time. Additional research is needed to understand the failure of this movement to improve along with all other groups. The learners in this case may have been unsure of the feedback wording provided or unable to alter their current movement pattern. The upright posture recommended by the Heads Up technique moves the torso out of parallel with the movement direction which may require more core strength to maintain stability on impact[280]. The upright position of the torso may also move the center of mass of the participant closer to their base of support. This action makes the tackler more stable and able to adjust to variations in the position of the target[281], but also decreases the forward momentum removing this force from the total amount of force that can be imparted on the target[282]. Any variable that reduces the ability to deliver a blow to the target may be resisted by the tackler, as they feel a harder impact is a better tackle.

As with any multi-joint feedback program, several of the movements may be intertwined. Cervical extension and trunk angle may be interdependent, which may have affected the ability of the learner to alter their movement pattern. If the tackler increases trunk angle, the needed cervical angle to continue to see the target gets lower. In this case, participants already having a high cervical angle may have limited the trunk angle utilized. Participants may have also continued to maintain a forward lumbar posture as a substitute for decreasing pelvic height. Feedback to bend the hips and knees to lower the center of mass may have prompted the participants to maintain forward lumbar flexion to accommodate the inability to bend at the hips, knees and ankles. Additional analysis should focus on the interdependence of each portion of the instructed movement profile.

All groups improved performance in decreasing pelvic height and step length over time yet there was no group that achieved a significantly greater change than others. Pelvic height is often referred to as lowering the center of gravity. This movement is an often taught standard of practice tackling across collision sports[283,284]. As previously stated, the verbal feedback for this motion may be understandable to the learners of this age group, making the video feedback extraneous. Step length was significantly improved over time with no treatment group significantly better than the others, though effect of self plus expert feedback did trend toward greater improvement. Long step length is a common mistake while tackling[283,284]. Participants may feel that they are able to make more forceful contact or close on the target faster with longer steps. Prevailing instructions recommend slowing the progression toward the target in order to insure a secure tackle is made[16]. This break down allows the tackler to adjust to last minute changes in direction by the ball carrier. In the case of this tackling methodology the function may be two fold, slowing the forward momentum to decrease the impact speed and allowing increased time prior to impact for the tackler to move their body into a position to deliver a blow safely.

Head placement results indicate tacklers regularly placed their head across the front of the target at baseline, after instruction and post treatment. Rugby style tackling recommends the tackler maintain the head on the side of attack[283]. This action is primarily to ensure the head of the tackler remains on the top hip and does not get trapped under the target. Participants appeared to instinctively move the head to the far side of the target at baseline, minimizing the need for corrective feedback. Participants who, rather than place the head on the near side or the far side of the target, would make contact with their head on the target may have introduced the discomfort associated with an impact on the face and head as an alternate feedback variable[285].

Limitations of this study include lower than expected effect size created by the video treatment and thusly small sample size. Future research should identify the effect of these feedback methodologies with larger and more diverse groups of participants. Additional research should examine additional feedback that may improve performance of the new techniques including providing a performance error measure of each variable. This study analyzed data collected over a one day period. Truly altering technique often requires longer duration practice and feedback opportunities[286] so expanded long term treatments must be undertaken to create true change in athletes. The use of a laboratory based design allows for improved control over data collection, but typical use of these programs will take place on the field. Future research should identify the plausibility and effect of performing these feedback interventions in a field environment

Improving tackling performance is critical to improving safety of youth football participants'. While organizations have recommended that a focus be placed on performance and have developed mechanisms they feel will increase safety, methods to instruct players in tackling performance have not been readily available. This research indicates that video feedback offers no significantly different advantage over verbal feedback alone. The mechanism of verbal feedback utilized in this study requires the participant to reflect on their previous practice bout as well as then providing verbal feedback on the parts of the total form that require adjustment. Additional research should address the individual differences in athletes that may affect the feedback given. These differences include both learning mechanisms and physical mechanisms that may alter the way a young athlete learns.

Chapter 5: The Effect of a Vertical Head up Style Tackling Training on Head Accelerations in Youth American Football Athletes.

Introduction

Reports estimate 1.6 to 3.8 million cases of concussion occur in sports and recreation each year in the US, with sports related concussion rate estimates between 0.19 and 1.78 per 100,000 participants[10,11]. Head contact during blocking and tackling are the most prevalent mechanism of injury or activity associated with concussion in American football [13]. Despite continued efforts to reduce the occurrence of concussion the incidence continues to increase[12]. Recent research is beginning to understand the effectiveness of the Heads Up Football instruction in reducing head accelerations and injury rates in youth football athletes[27]. Previous research does not separate the effectiveness of the coaches' education program, practice restrictions and the tackling technique instructed in these programs.

Concussion rates for youth football athletes per the Youth Football Surveillance Network accounted for 9.6% of all injuries in youth football[22]. The injury rate at this level in game play was 2.38 to 6.16 per 1000 athlete exposures (AE) and 0.24 to 0.59 per 1000 AE in practice[19,22]. The median and 95th percentile linear acceleration and rotational acceleration for 9-12 year old athletes was significantly different between games and practices, with game accelerations being higher[23]. This trend does not carry forward into

12-14 year olds, who show no difference in accelerations experienced between practice and games[24].

Recent research may indicate the effectiveness of the Heads Up Football instruction (Appendix B) in reducing head accelerations and injury rates in youth football athletes. Heads Up Football (HUF) league coaches receive hands on training regarding proper equipment fitting, didactic and participant demonstration of proper tackling technique and instruction in drills that reduce head contact[27]. Participants in HUF leagues experienced less head impacts during practice registering both 10 and 20g's when compared to non-HUF leagues[27]. The HUF leagues also saw a decrease in practice injury rates when compared to non-HUF leagues[28]. The Qualitative Youth Tackling Scale (QYTS) is a visually observed objective scale created to instruct the tackling form recommended by USAFootball. This scale is designed to provide feedback on the components of the technique believed to be most related to safety while maintaining performance. Utilization of HUF practice recommendations shows the ability to decrease injury risk in youth athletes, though the effect of the tackling technique may not be the primary driver or may not translate to game performance. The purpose of this study was to examine the effects of training in a vertical heads up tackling style on the number of head accelerations experienced while tackling in a controlled laboratory situation. Utilizing this technique has been recommended by USAFootball to reduce the risk of head and neck injury while tackling. A reduction in the head accelerations experienced by the tacklers may indicate a decreased risk for sports related concussion. Reducing contact of the head while tackling and achieving the proper body position is expected to reduce the head accelerations experienced by participants. We believe participants who are trained in the Heads Up tackling technique will experience decreased head accelerations when tackling.

Methods

Participants with previous football experience were recruited from youth football organizations in the local area. Demographic data were collected including: age, height, weight, sex, school level, and seasons playing tackle football. Training and testing took place over a one day period. Twenty four participants (11.5 ± 0.6 years old, 60.5 ± 2.2 in, 110 ± 18.4 lbs.) completed the one day training session on tackling technique. These participants had 3.3± 1.5 years of football experience. Head accelerations were analyzed for the baseline and end of training time points. The tackling task included three baseline tackles and four training blocks of three tackles each in the motion capture volume in which the learner and the target are offset one foot at a distance of five feet. The target for this testing was a 90 pound stand-up tackling dummy with the center of mass near the contact area which was specifically designed for this research (Appendix A) placed 5 yards in front of the participant (Figure 15). At the baseline time point, the participants were instructed to tackle the dummy as they typically do when playing football. Participants were then given instruction on the six standard components the USAFootball tackling style which are contained in the Qualitative Youth Tackling Scale (QYTS), after which they will perform three tackles. Designed in conjunction with USAFootball, the QYTS provides a feedback framework containing six components of a safe and effective vertical tackling style[27] that can be assessed as either a successful or unsuccessful

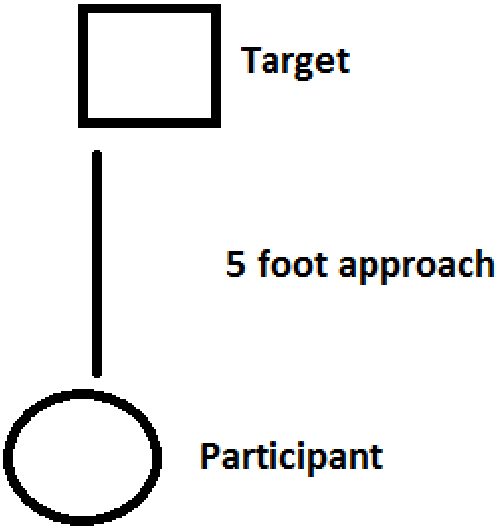


Figure 15. Participants starting position relative to target.

movement. Feedback from the video and QYTS was then provided in four blocks of three trials. The participants were asked to identify the portions of the tackling movement that they performed correctly. Verbal feedback was provided by the researcher based on the errors assessed. The top two errors based on player safety from QYTS was provided verbally to the participant (Appendix B). Participants were given access to a 17x10 inch computer screen for viewing of all feedback videos. The video in which the participant made errors that were located higher in order of importance on the list of tackling form components was utilized for feedback at the end of each block. They were then allowed time to view the feedback video four times. The video presented of the participant was updated after each block to present the videos of trials performed during the previous practice block. The number of repetitions of feedback was the same for all participants. Head acceleration data were collected utilizing the acceleration data captured by the xPatch system. Two xPatch systems were applied bilaterally to the participant’s mastoid processes utilizing manufacturer provided adhesive patches. The threshold for recording impacts was set at 6g’s for each device.

Data Analysis

At the end of data collection the data were downloaded from the device into the X2 Impact Monitoring system using the manufacturer’s procedure. The data were uploaded and processed utilizing the system software which adjusts measures based on right and left head side device placement, making right and left side data comparable, and translates the measurements to the center of mass of the head. Peak linear acceleration measures as calculated by the system were downloaded to an Excel spreadsheet. Also included in this spreadsheet were: the time of impact, location, duration and Clack measurement. The Clack measurement is an algorithm utilized by the monitoring system to distinguish true impacts from accidental bumping or dropping of the device. All impacts were downloaded regardless of the Clack measurement.

Impacts were identified by comparing the timestamp reported by the xPatch device and a monitor placed in view of video recording of the data collection. The time stamp on the xPatch and the monitor were synced immediately prior to initiation of data collection. The monitor and the xPatch were both capable of displaying the time to within 1/100th of a second. True impacts from the left and the right xPatch were identified from the full list of all six g and above recordings using the inset time stamp. Once isolated the peak linear accelerations from each trial were averaged. If two impacts took place in rapid succession the first of the impacts was utilized, as the second impact is likely caused by contact with the ground at the completion of the movement which is not the focus of this study.

Statistical analyses consisted of a Wilcoxon Signed Ranks Test to determine the effect of training on participant counts of head accelerations over 10g's at pretest and post-test time points. An additional Wilcoxon Signed Ranks Test was performed to determine the effect of training on participant scores of the QYTS at pretest and post-test time points. A Mann-Whitney *U* test was performed to evaluate if a difference exists between QYTS scores of those who experience head accelerations greater or less than 10gs. Statistical significance values were set at *a priori* $p \leq 0.05$ for all tests. Odds ratios comparing the successful performance of the individual skills of the QYTS to head accelerations over 10, 15, 20 and 25g's were also completed.

Results

In the 72 tackles performed during the baseline testing, 30 head accelerations over 10g's were experienced by the participants. This number accounted for an average of 1.2± 0.9 per participant. This number ranged from 3 impacts to 0 impacts per participant. After training a total of 15 head accelerations over 10g's were reported by the xPatch system. This number accounted for an average of 0.6± .7 per participant (Figure 16). This number ranged from 2 impacts to 0 impacts per participant. Results of the Wilcoxon Signed Ranks Test indicated a significant difference between these two time points, p=0.027.

To compare the outcomes of change in performance between baseline and the end of training, the participant's movement profile was dichotomized for each aspect of the QYTS. The dichotomized score was summed to create an overall score for each tackle. A Wilcoxon Signed Rank Test was performed between the two time points. This test indicates a difference in the total score between the baseline and end of training time points, p=.004. The average QYTS score improved from 1.50 ± 1.10 to 2.46 ± 1.31.

In examination of all head acceleration data points, a Mann Whitney test found no significant difference (p=.987) in QYTS scores during tackles in which the participant's head acceleration measurement was over 10g's when compared to those tackles that were below the 10g threshold. Odds ratios (Table 7) calculated for all movements found increased odds of having head acceleration greater than 10g’s when participants had an average step length greater than 75% of standing pelvis height (2.28, 95%CI: 1.29-4.05). Results for trunk inclination greater than 55 degrees or less than 35 degrees (1.09, 95% CI: 0.61-1.96), cervical extension less than 45 degrees (0.96, 95%CI: 0.57-1.62) pelvis height greater than 75% of standing pelvis height (1.68, 95%CI: .93-3.01) and shoulder extension on approach less than 45 degrees (0.61, 95%CI: .35-1.08) were non-significant. The odds of sustaining an impact over 15g (4.42, 95%CI: 1.80-10.80) and 20g (4.14, 95%CI: 1.40-12.29) were also increased with a step length greater than 75% of pelvis height and for pelvis height over 75% of standing at 15g’s (3.10, 95%CI: 1.26-7.61).

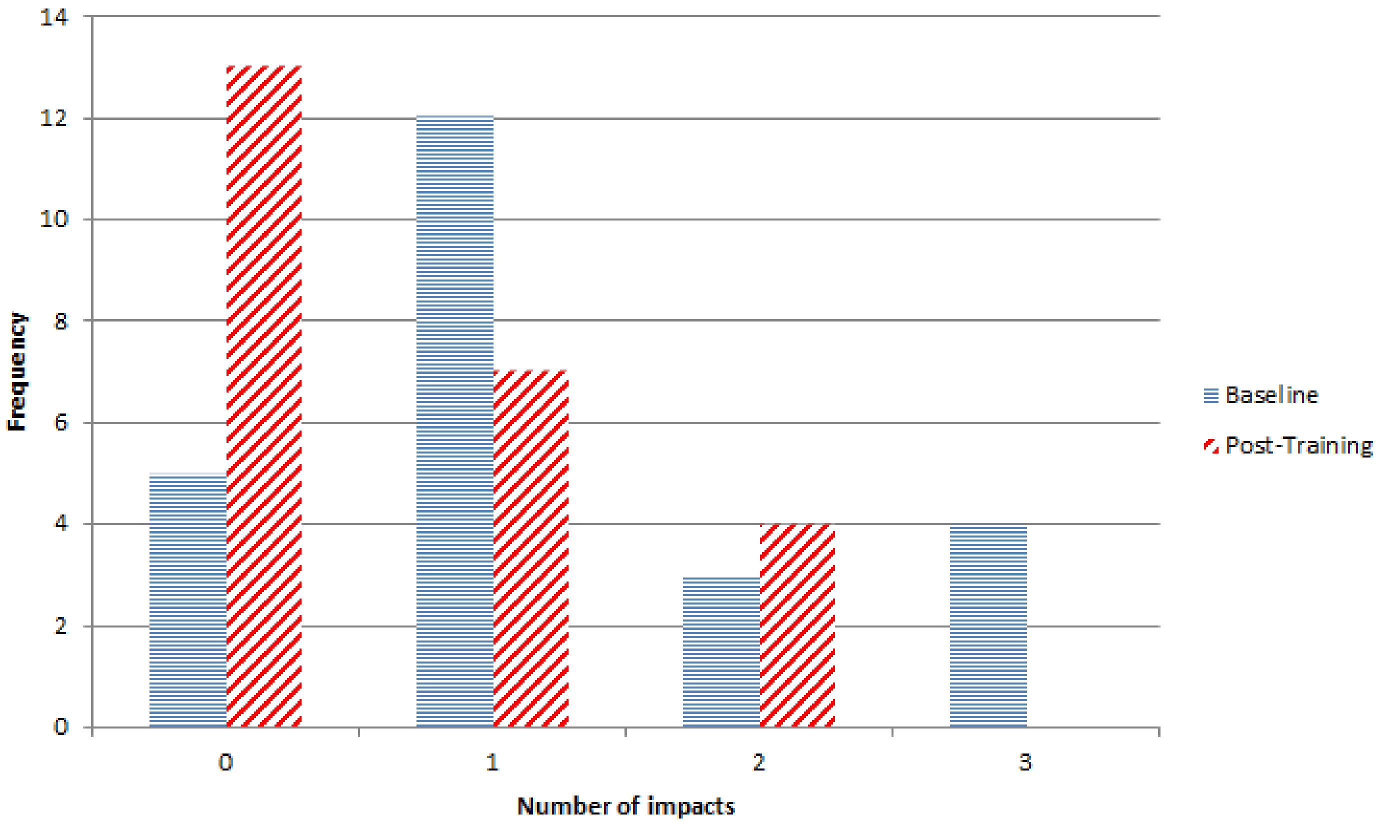


Figure 16. Frequency of head impacts over 10gs per block at baseline and post-training time points.

Table 7. Odds ratios of experiencing head acceleration over 10, 15 and 20g's by failed performance of QYTS items. Significant odds ratio indicated by reddened section.

	10G	15G	20G
Cervical Extension	0.96 95%CI:0.57-1.62	1.46 95%CI:0.73-2.89	0.89 95%CI:0.41-1.98
Trunk Inclination	1.09 95%CI:0.61-1.96	1.88 95%CI:0.80-4.41	2.20 95%CI:0.74-6.55
Head Placement	1.46 95%CI:0.59-2.59	0.63 95%CI:0.14-2.79	0.5 95%CI:0.65-3.90
Pelvic Height	1.68 95%CI:0.93-3.01	3.10 95%CI:1.26-7.61	2.2 95%CI:0.82-6.02
Shoulder Extension	0.61 95%CI:0.35-1.08	0.32 95%CI:0.13-0.75	0.37 95%CI:0.14-1.01
Step Length	2.28 95%CI:1.29-4.05	4.42 95%CI:1.80-10.80	4.14 95%CI:1.40-12.39

Discussion

The results of this study indicate training in a head up, upright style tackle reduces the number of head accelerations over 10g's experienced by the tackler. Previous research has indicated the effectiveness of the Heads Up framework to decreased head accelerations over 10g's experienced by tacklers[28]. The results found here indicate that the tackling form instructed may play a role in these findings. Concurrently with the decrease in head accelerations, the participants' form scores on the QYTS improved from baseline to post training. Results indicated those who took shorter steps toward the target had decreased odds ratios of receiving an impact greater than 10, 15 and 20g's. The one day training session the participants' received was capable of decreasing the head accelerations experienced at post training.

Analysis of changes in form indicates the training program was successful in improving the QYTS scores of the athletes over a one day period. Of these changes in form, a significant increase in the odds ratio of suffering an impact over 10, 15 and 20g's was found in in those who failed to reduce their step length the less than 75% of standing pelvis height. This result may indicate that slowing the body in general decreases the head accelerations experienced[41] or increases the time of approach, allowing the tackler to achieve better form as they apply the tackle[283]. Other portions of the QYTS may show higher odds of head accelerations above 15 and 20gs, but these data had few impacts above those levels possibly due to the laboratory design as well as the age of the participants.

Linear accelerations and rotational acceleration/velocity have been proposed as the causative factors of concussive injuries[287], with a significant relationship between linear and rotational components[288]. Previously only impacts that resulted in a concussion were seen as dangerous[289]. As knowledge regarding head injuries increases, the role of subconcussive blows in long term health effects has become better known[290]. Research has indicated the effect of subconcussive impact includes increased risk of mild cognitive impairment and chronic traumatic encephalopathy (CTE)[291]. Providing a form structure that limits both high level impacts and subconcussive blows may lead to reduced concussive injury rates and long term cognitive issues. The results of this study indicate a training program in tackling form is capable of significantly decreasing the number of head contacts over 10g's.

The goal of many programs and rule changes has been the reduction of the number and severity of head contacts through decreasing the number of contact practices[292], coach's education[28] and implementation of form instruction[8] and cervical strengthening[37]. These studies have utilized a number of mechanisms including conducting drills with helmets removed to create a risk adverse environment[285] and a comprehensive coaches' education framework to limit the head impact exposure of football players[16,27]. To date both of these programs have shown promise in reducing the impact exposure of players.

Limitations to this study include a restricted age range and the use of a laboratory environment. Additional work should look to expand scope both in number and age range. The translation of these results to both a controlled dynamic and real life environment should be completed. Additional analysis should identify the components of the tackling form that influence the head accelerations experienced by the tackler in order to determine the source of changes in head accelerations found in this study.

The performance of a tackle that minimizes head accelerations is critical to the safety of the athletes in youth football. The results of this study indicate training in a head up vertical style tackle reduces the head accelerations experienced by tacklers in a laboratory setting against a stationary target. These results are critical to determining a form that minimizes the head accelerations experienced. These results provide a baseline from which additional research should be planned to translate these results to a field based dynamic environment.

Chapter 6: Additional Analyses and Future Directions

The three previous chapters have presented a proposed system to alter the tackling mechanics of youth football players for the purpose of reducing head acceleration exposure. Chapter 2 presented an analysis of validity and intrarater agreement of a system of verbal feedback. The results of this chapter found raters are capable of providing accurate and consistent feedback between raters at or above the levels reported in the literature for most of the movements. Raters with experience visually assessing movement provided more accurate and higher rates of agreement than raters with little to no experience. Chapter 3 presented an analysis of model utilized when providing video feedback on tackling form to youth athletes. The results of this chapter indicate no significant difference between model types in the ability to improve tackling form. All treatment groups saw improvement over time in four of the six components analyzed. This outcome may be interpreted as the effective component of the feedback protocol was the reflective verbal feedback provided to all participants. Chapter 4 presented an analysis of the effectiveness of the training program in reducing the number of head accelerations experienced between the baseline and post training time points. The results of this study indicate training in a head up, vertical tackling style was effective in reducing the number of head accelerations experienced by participants after a 1 day training program. Participants experience roughly half the number of head accelerations over 10g's after training. The odds of sustaining an impact over 10, 15, and 20g's was increased in those with a step length above 75% of standing pelvis height. The results of all of these studies combined provide a framework to begin a training program aimed at reducing the impact load experienced by youth football athletes by providing an effective tackling form and a mechanism in which to provide feedback.

Additional Analyses

Analysis of number of head accelerations over 10g's experienced by the treatment groups was also conducted for the one day testing protocol. A Kruskal-Wallis test indicated no difference between groups at Baseline (p= 0.383), Instruction (p= 0.457), and Post-training time points (p= 0.336). The treatment provided to the participants did not influence the effectiveness of the training to decrease the number of head accelerations experienced by the participants. As seen in the previous sections the effect of model on performance of the movement skill was non-significant. This result is also seen in the head acceleration data.

In order to identify if additional concussion risk variables were effected by training the changes in peak rotational acceleration where also analyzed between baseline, instruction and post training. A median split was utilized to determine a cut point to dichotomize the outcomes, this point was 1885 degrees/sec. Twenty seven impacts over this point were reported at baseline, this number dropped to nine post training. A Friendman test indicated a significant change in these results (p= 0.031). These results indicate that not only were the peak linear accelerations decreased by training, so were the peak rotational accelerations. The training did not introduce an impact mechanism that would have separately increased rotational acceleration without increasing linear acceleration measures.

Correlational analysis of performance data with head acceleration data indicates a weak correlation between step length and concussion variables of interest (Table 8). This relationship continues when partial correlations are calculated utilizing head (Table 9) and pelvis velocity (Table 10) measured at contact. The positive correlation indicates that as percentage of step length increases so do the values for peak linear acceleration (r=0159, p=0.001), peak rotational acceleration (r=.164, p=0.001), peak rotational velocity (r=.152, p=0.002) and HIC_{15} (r=.155, p=0.001). No other variables have a significant relationship to any of the concussion variables. The results of this analysis along with the results of chapter 5 indicate shoulder position, cervical angle, pelvis height and placement of the head across the front of the target may not significantly impact the head accelerations experienced by tacklers.

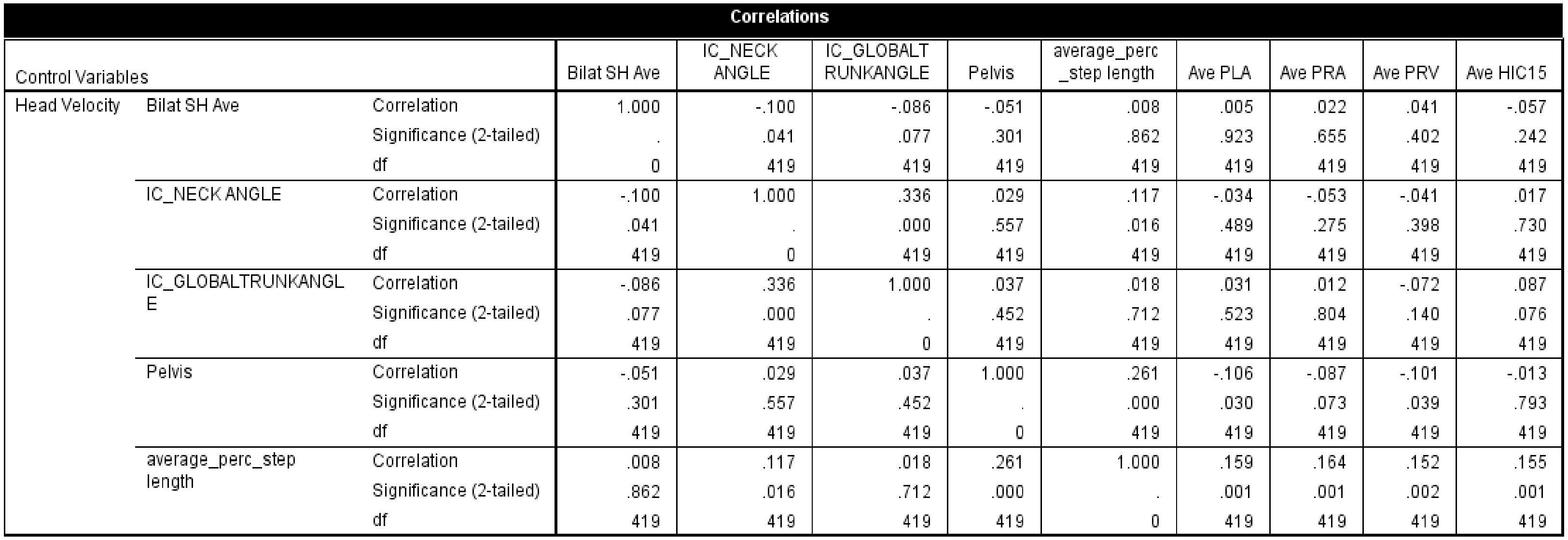
Analysis of head acceleration data from participants who performed a three session training program indicated the same outcomes as those who performed a one day training after a 24 hour retention period. Thirteen subjects participated in the four session training completed over one week. At baseline, participants experienced 24 impacts over 10g's in the 65 tackles completed. After training this number decreased to 6 impacts over 10g's experienced by the participant after a 24 hour retention period. The results of a Wilcoxon signed ranks test indicate a significant difference (p=0.026) between baseline and post training impact count over 10g's. These results indicate an effect of training that is able to be retained for at least a 24 hour period. This retention indicates coaches can expect tackling training to carry forward for at least 24 hours after the last practice period.

Table 8. Correlations between movement variables and concussion risk variables.

Correlations

		Bilat SH Ave	IC_NECK ANGLE	IC_GLOBALTRUNKANGLE	Pelvis	average_perc_step length	Ave PLA	Ave PRA	Ave PRV	Ave HIC15
Bilat SH Ave	Pearson Correlation	1	-.080	-.125	-.121	-.094	-.033	-.001	.009	-.055
	Sig. (2-tailed)		.084	.007	.012	.052	.481	.979	.852	.236
	N	470	468	468	429	423	470	470	470	470
IC_NECK ANGLE	Pearson Correlation	-.080	1	.330	.043	.125	-.009	-.023	-.012	.024
	Sig. (2-tailed)	.084		.000	.373	.010	.849	.622	.800	.607
	N	468	469	469	429	423	469	469	469	469
IC_GLOBALTRUNKANGLE	Pearson Correlation	-.125	.330	1	.078	.071	.024	.014	-.077	.073
	Sig. (2-tailed)	.007	.000		.107	.143	.603	.767	.095	.115
	N	468	469	469	429	423	469	469	469	469
Pelvis	Pearson Correlation	-.121	.043	.078	1	.351	.019	.021	.022	.025
	Sig. (2-tailed)	.012	.373	.107		.000	.689	.656	.640	.606
	N	429	429	429	438	425	438	438	438	438
average_perc_step length	Pearson Correlation	-.094	.125	.071	.351	1	.195	.184	.178	.152
	Sig. (2-tailed)	.052	.010	.143	.000		.000	.000	.000	.002
	N	423	423	423	425	425	425	425	425	425

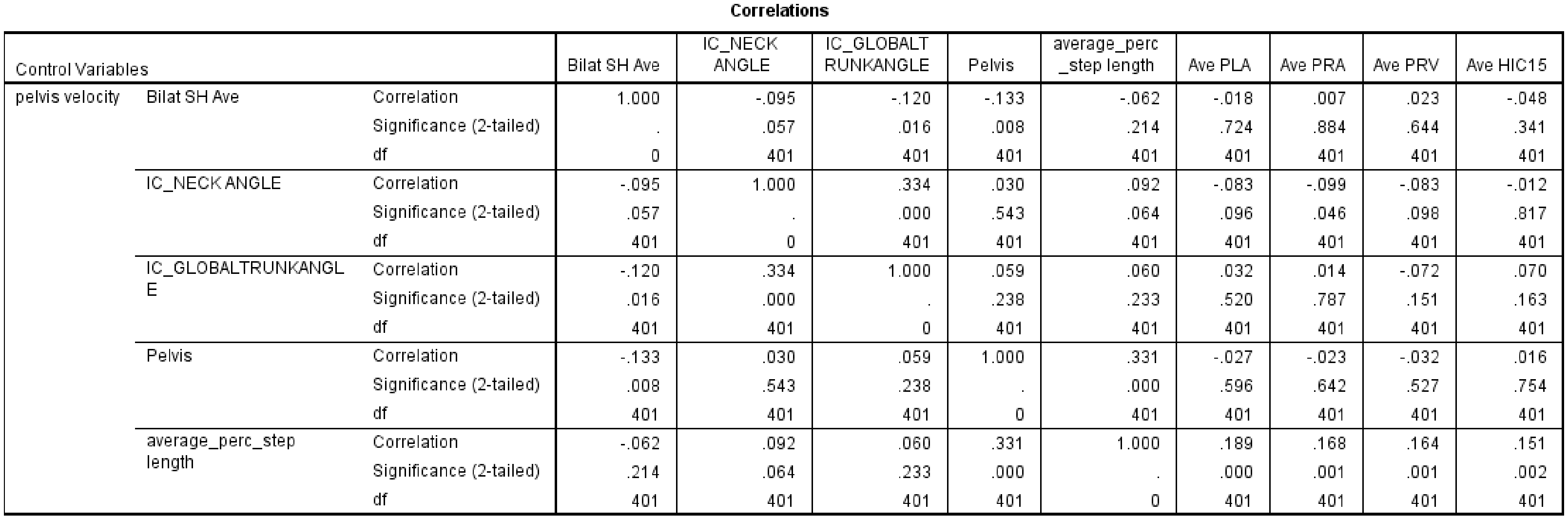
Table 9. Partial correlation of movements and concussion risk variables when accounting for head velocity.



Correlations

Control Variables			Bilat SH Ave	IC_NECK ANGLE	IC_GLOBALT RUNKANGLE	Pelvis	average_perc _step length	Ave PLA	Ave PRA	Ave PRV	Ave HIC15
Head Velocity	Bilat SH Ave	Correlation	1.000	-.100	-.086	-.051	.008	.005	.022	.041	-.057
		Significance (2-tailed)	.	.041	.077	.301	.862	.923	.655	.402	.242
		df	0	419	419	419	419	419	419	419	419
	IC_NECK ANGLE	Correlation	-.100	1.000	.336	.029	.117	-.034	-.053	-.041	.017
		Significance (2-tailed)	.041	.	.000	.557	.016	.489	.275	.398	.730
		df	419	0	419	419	419	419	419	419	419
	IC_GLOBALTRUNKANGLE	Correlation	-.086	.336	1.000	.037	.018	.031	.012	-.072	.087
		Significance (2-tailed)	.077	.000	.	.452	.712	.523	.804	.140	.076
		df	419	419	0	419	419	419	419	419	419
	Pelvis	Correlation	-.051	.029	.037	1.000	.261	-.106	-.087	-.101	-.013
		Significance (2-tailed)	.301	.557	.452	.	.000	.030	.073	.039	.793
		df	419	419	419	0	419	419	419	419	419
	average_perc_step length	Correlation	.008	.117	.018	.261	1.000	.159	.164	.152	.155
		Significance (2-tailed)	.862	.016	.712	.000	.	.001	.001	.002	.001
		df	419	419	419	419	0	419	419	419	419

Table 10. Partial correlation of movements and concussion risk variables when accounting for pelvis velocity



Correlations

Control Variables			Bilat SH Ave	IC_NECK ANGLE	IC_GLOBALT RUNKANGLE	Pelvis	average_perc _step length	Ave PLA	Ave PRA	Ave PRV	Ave HIC15
pelvis velocity	Bilat SH Ave	Correlation	1.000	-.095	-.120	-.133	-.062	-.018	.007	.023	-.048
		Significance (2-tailed)	.	.057	.016	.008	.214	.724	.884	.644	.341
		df	0	401	401	401	401	401	401	401	401
	IC_NECK ANGLE	Correlation	-.095	1.000	.334	.030	.092	-.083	-.099	-.083	-.012
		Significance (2-tailed)	.057	.	.000	.543	.064	.096	.046	.098	.817
		df	401	0	401	401	401	401	401	401	401
	IC_GLOBALTRUNKANGLE	Correlation	-.120	.334	1.000	.059	.060	.032	.014	-.072	.070
		Significance (2-tailed)	.016	.000	.	.238	.233	.520	.787	.151	.163
		df	401	401	0	401	401	401	401	401	401
	Pelvis	Correlation	-.133	.030	.059	1.000	.331	-.027	-.023	-.032	.016
		Significance (2-tailed)	.008	.543	.238	.	.000	.596	.642	.527	.754
		df	401	401	401	0	401	401	401	401	401
	average_perc_step length	Correlation	-.062	.092	.060	.331	1.000	.189	.168	.164	.151
		Significance (2-tailed)	.214	.064	.233	.000	.	.000	.001	.001	.002
		df	401	401	401	401	0	401	401	401	401

Utility

The combined results of this study lay the ground work for development of programs to address the high concussion rates in football. Instruction and training in a head up, vertical tackling style is capable of reducing the number of head impacts experienced by athletes. The mechanisms used to provide feedback in this tackling style can be utilized by coaches easily and inexpensively. Coaches have a limited time in which to teach proper tackling technique due to the number of additional items that must be taught during a practice. Providing coaches with a quick and standardized method to instruct proper tackling form is extremely useful for this audience.

Implications

The results of this study indicate that training in a head up vertical tackling style are effective in reducing the number of head impacts over 10g's experienced by participants. The verbal feedback provided to the participants may in fact be the driving factor in altering the performance variables studied. Coaches, trainers and athletic trainers with experience evaluating movement may provide more accurate verbal feedback to the athletes, which would increase the effectiveness of the intervention. Of the movements studied within these chapters, decreasing step length prior to the tackle is the only variable indicated to decrease the risk of head accelerations over 10g's.

Future directions

Future directions for this research will include an expansion of all laboratory based assessments to the field level. The addition of coaches to the intrarater training as well as the inclusion of interrater reliability should be completed for the QYTS. Future work on the QYTS should also focus of the establishment of content validity utilizing a panel of experts. While the results of the study of the effectiveness of model type utilized in video feedback did not identify one model type to be more effective than the others additional work should identify this effect in a larger more diverse population as well as on the field effectiveness. Additional research should identify the effectiveness of these programs on long term retention and transfer of the skills. While this research identified a head up, vertical tackling style as effective in decreasing the number of peak linear head accelerations over 10g's, additional research should continue to identify the cause of this change in head accelerations experienced. Based on this research, step length is the only variable that significantly alters the odds of experiencing a head acceleration over 10g's.

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Appendix A: Data Sheet

OSU Tackle Testing Data Sheet

ID Number: ___________________ **Birthdate: _________________**

Height: _______________________ **Weight: ___________________**

Sex: ______________________ **Grade: ____________________**

Seasons of Football Played: ________ **Group Assignment: ________**

Mocap Number_________________

History of Musculoskeletal Injury or Concussion:

____

____

____

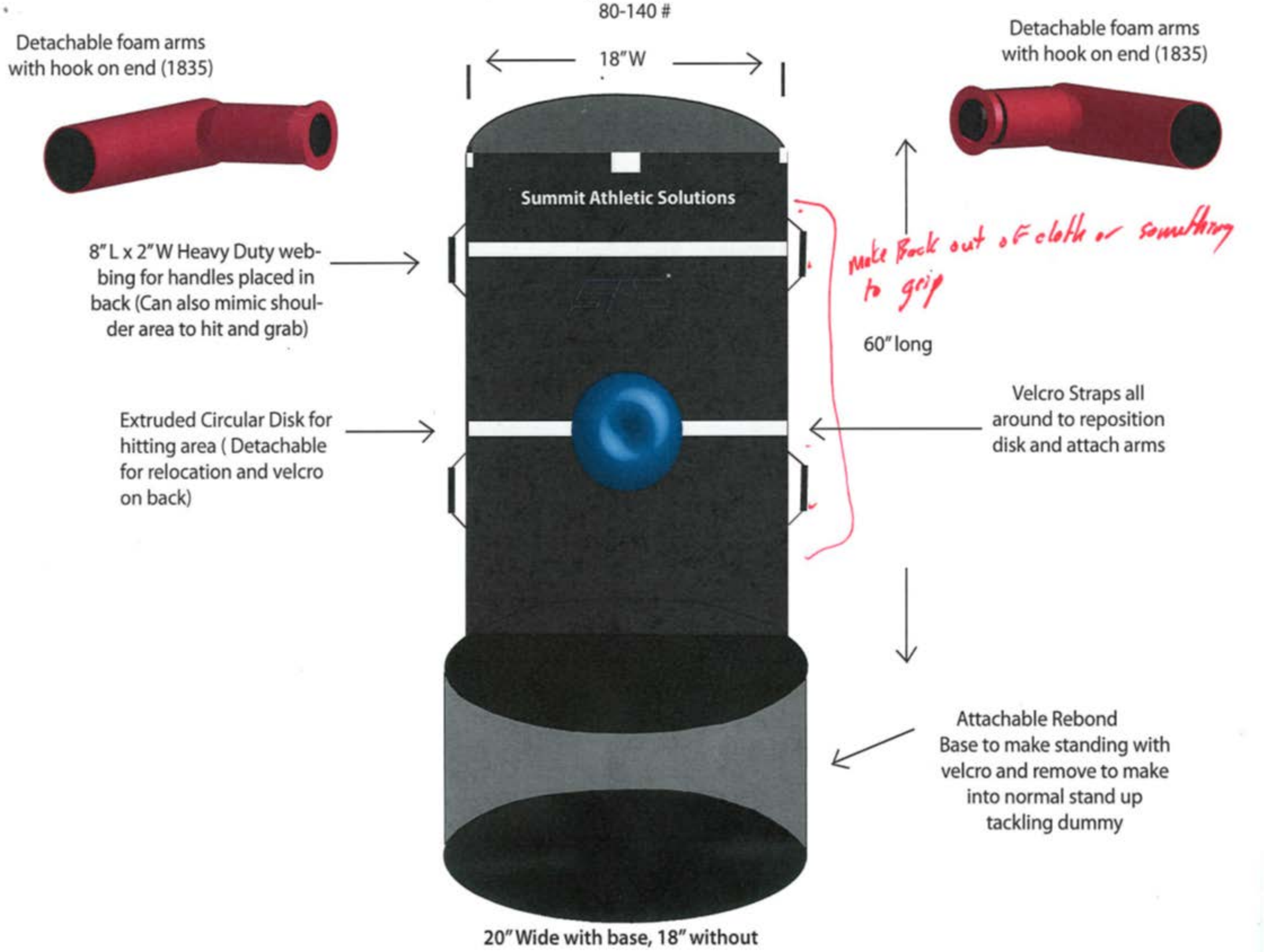
____

Appendix B: Feedback Sheet

Tackling Movement Score and Feedback Sheet USA Football
__ 1. Head up, eyes toward target. (Cervical extension)
__ 2. Contact with the front of the shoulder (Trunk Angle)
__ 3. Head across to far side of target (Head Placement)
__ 4. Hips and knees bent to lower center of gravity (Pelvic Height)
__ 5. Arms back and follow an upward movement on contact (Shoulder extension)
__ 6. Short steps toward target (Step length)

Appendix C: Dummy Schematic

Football Dummy Concept 1



Weight Range from
80-140 #

18"W

Detachable foam arms
with hook on end (1835)

Detachable foam arms
with hook on end (1835)

Summit Athletic Solutions

8" L x 2" W Heavy Duty webbing for handles placed in back (Can also mimic shoulder area to hit and grab)

make Back out of cloth or something
to grip

60" long

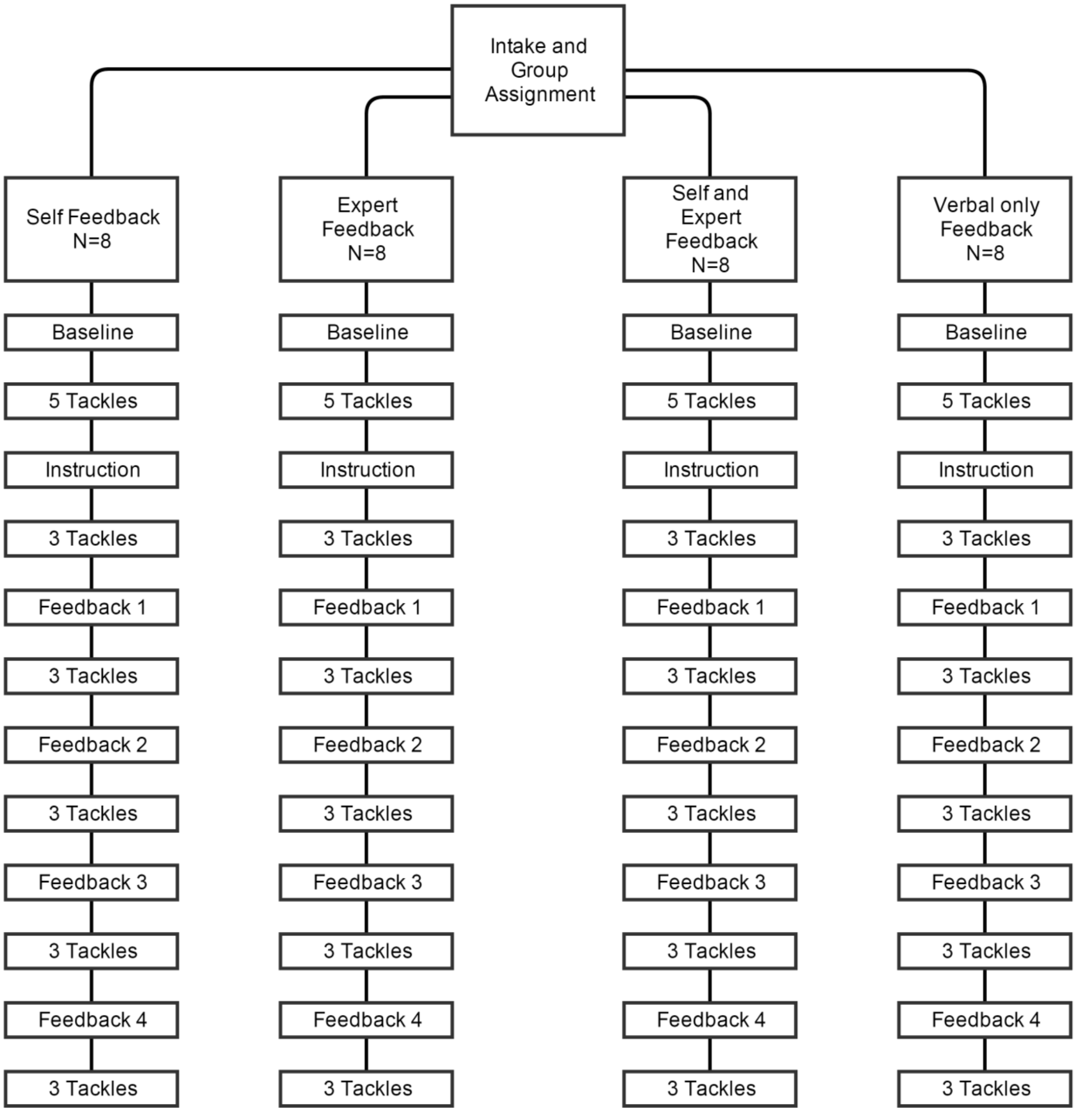
Extruded Circular Disk for hitting area (Detachable for relocation and velcro on back)

Velcro Straps all around to reposition disk and attach arms

Attachable Rebond
Base to make standing with
velcro and remove to make
into normal stand up
tackling dummy

20" Wide with base, 18" without

Appendix D: Feedback Schedule and Grouping Diagram


Intake and Group Assignment
Self Feedback N=8
Expert Feedback N=8
Self and Expert Feedback N=8
Verbal only Feedback N=8
Baseline
5 Tackles
Instruction
3 Tackles
Feedback 1
3 Tackles
Feedback 2
3 Tackles
Feedback 3
3 Tackles
Feedback 4
3 Tackles

Appendix E: Feedback Views by Feedback Condition

Self Feedback

Expert Feedback

Self Plus Expert