ISSN 1750-9823 (print)
International Journal of Sports Science and Engineering
Vol. 06 (2012) No. 03, pp. 131-140

Investigation of the Effects of Cervical Strength Training on Neck Strength, EMG, and Head Kinematics during a Football Tackle

Pete Lisman[1], Joseph F. Signorile[1], Gianluca Del Rossi[2], Shihab Asfour[1], Moataz Eltoukhy[1], Damon Stambolian[1], Kevin Allen Jacobs[1]

[1] University of Miami, Coral Gables, Fl
[2] University of South Florida, Tampa, Fl

(*Received October 12, 2011, accepted October 20, 2011*)

Abstract. Increasing the strength of the cervical musculature has been suggested as a means of attenuating the acceleration forces that cause concussions in sports such as football. The purpose of this study was to examine the effects of an eight-week isoinertial cervical resistance training program on the electromyographic (EMG) activity of the sternocleidomastoid (SCM) and upper trapezius (UT) as well as the kinematics of the head and neck in response to a football tackle. Sixteen college-aged males (21.6 ± 2.8 yrs) with previous high school football playing experience completed an eight-week isoinertial cervical resistance-training program consisting of three sets of 10 repetitions of neck extension, flexion, and right and left lateral flexion at 60-80% of 10 repetition maximum (RM), two to three times per week. Isometric cervical strength, neck girth, and both the EMG and kinematic responses of the head and neck during tackling were measured before and after training. All kinematic data were gathered using a ViconNexus® 3D motion capturing system. Statistical analyses of EMG and kinematic data were performed by utilizing an ANCOVA with repeated measures (level of significance was set at $p < 0.05$). Training resulted in 7 and 10% increases ($p < 0.05$) in isometric cervical extension and left lateral flexion strength, respectively, but had no influence on the EMG responses of the SCM or UT, peak linear or angular head accelerations during tackling. The UT demonstrated approximately 40% higher absolute EMG activity than the SCM during tackling both before and after training. This study showed that despite modest training-induced improvements in isometric cervical strength, the eight-week isoinertial cervical resistance training program failed to augment dynamic stabilization of the head and neck during a football tackle.

Keywords: concussion; exercise; cervical; electromyography; kinematics

1. Introduction

The risk of concussion injuries associated with football is of particular concern given the increased susceptibility of the affected athlete to future injuries and the potential for long-term health problems. Every year about 300,000 sports-related concussions occur in the United States with the highest percentage occurring in the sport of football (Bailes & Cantu, 2001). College football players with multiple concussions are up to three times more likely to suffer a future concussive injury than those with no previous history (Guskiewicz et al., 2003). Additionally, retired professional football players with a history of three or more concussions are 3-5 times more likely to develop late-life mild cognitive impairment, depression, and significant memory problems than those with less than three concussions (Guskiewicz et al., 2005; Guskiewicz et al., 2007). Given the high incidence of sports-related concussions and their potential to lead to long-term health problems, an improved understanding of the factors that contribute to their occurrence is critical.

The two major mechanisms of concussion are direct impacts of the head and sudden acceleration or deceleration of the torso that is transferred to the head and neck indirectly. These impacts result in linear and/or angular acceleration of the head that may lead to neuropathological changes and subsequent neuronal injury (Cantu, 2000; McCrory et al., 2001). Both early reports (Naunheim et al., 2000) and more recent studies utilizing helmets instrumented with linear accelerometers (Brolinson et al., 2006; Duma et al., 2005; Guskiewicz et al., 2007; Mihalik et al., 2007) agree that average linear head acceleration associated with football play impacts range between 21-32 *g*. Concussion-inducing impacts in Division I collegiate football players have been measured to range from 56-169 *g* (Brolinson et al., 2006; Duma et al., 2005; Guskiewicz et al., 2007; Mihalik et al., 2007) which often exceeds the injury threshold of 70-75 *g* proposed by some researchers (Pellman et al., 2003; Viano et al., 2007).

The SCM and UT have been reported to be the primary dynamic stabilizers of the head and neck and likely attenuate head acceleration and/or absorb energy with direct and indirect impacts (Cantu, 2000; Cross & Serenelli, 2003; Tierney et al., 2005). Increasing the strength of the SCM and UT may reduce the incidence and severity of concussions. Increasing the neck stiffness of test dummies to simulate an increase in neck strength and girth, NFL laboratory reconstructions reported up to a 35% decrease in the head injury tolerance level specified by the National Highway Traffic Safety Administration. This decrease in head and neck injury risk was attributed to the significant reduction in peak head acceleration, velocity, and displacement (Viano et al., 2007). However, there are few controlled studies that have examined the effectiveness of cervical strength training in decreasing head acceleration in sport-specific activities. In a study examining the impact of resistance training on the cervical strength of male and female collegiate soccer players, a significant increase in strength was detected, but with no effect on any EMG or kinematic variables in response to forced cervical extension and flexion (Mansell et al., 2005). To date, no research has examined the effects of cervical resistance-training in football players on the EMG and kinematic responses to a tackling motion. Therefore, the purpose of this study was to examine the effects of an eight-week isoinertial cervical resistance training program on the EMG of the neck musculature and the kinematics of the head and neck in response to a standardized football tackle in college-aged males.

2. Methods

2.1. Subjects

Sixteen college-aged males, with high school football playing experience, were recruited using posted flyers. All potential participants completed a health status questionnaire and were included in the study if they were in good health and had no history of neurological disorders, cardiovascular disease, recent (< 6 months) history of concussion and/or neck injury, or any other orthopedic problem that would be aggravated or limit their capacity to complete the cervical resistance training program or a standard football tackle. In addition, subjects could not be participating in a cervical resistance training program and agreed not to perform any additional neck strength training exercises outside of the study's training regimen throughout their participation. Full demographic data on the participants are shown in Table 1. Each subject signed an informed consent and the research protocol was approved by the university's Institutional Review Board.

Table 1. Anthropometric data of the subjects

Variable	Mean ± SD
Age, yr	21.6 ± 2.8
Height, cm	182.5 ± 6.0
Mass, kg	94.6 ± 13.3

Values are means ± SD; N = 16.

2.2. Experimental Design

Using a case series design, the EMG and kinematic responses to a football tackle were assessed before and after the eight-week cervical resistance training program. The independent variable was session (pre-training vs. post-training) while the dependent variables were isometric cervical strength (extension, flexion, right and left lateral flexion), neck girth, EMG measurements of peak amplitude of the SCM and UT muscles, and kinematic measurements of peak linear and angular head acceleration, head-cervical angular displacement, and time to peak acceleration.

2.3. Cervical Resistance Training Program

All subjects participated in the eight-week cervical resistance training program. Training frequency consisted of two sessions per week for the first four weeks followed by three sessions per week for the last four weeks. Participants were instructed on proper performance of cervical extension, flexion, and right and left lateral flexion on the selectorized Pro 4-way neck machine. Individual seat height adjustments were made and recorded for use during subsequent training sessions. The primary investigator monitored the exercises to ensure proper form and range of motion for movements. The initial weight used during training was determined using a 10-RM test. During the first two weeks of training, 60% of 10 RM was used as the resistance and weight was increased 5% of the 10 RM every two weeks. Subjects performed three sets of 10 repetitions for extension, flexion, right and left lateral flexion in this order. Subjects rested 60 s between sets.

2.4. Testing Protocols

Anthropometric and Isometric Cervical Strength Assessment

Participant height, weight, neck girth, and isometric cervical strength were assessed at baseline and within one week of completion of the cervical resistance training program. Neck girth was measured just superior of the thyroid cartilage using a metric tape measure. Prior to assessment of isometric cervical strength, subjects performed a series of warm-up exercises consisting of 15 s of active clockwise and counterclockwise cervical rotations. This was immediately followed by two repetitions each of 15 s cervical extension, flexion, and lateral flexion active stretching. A digital force gauge (Chatillon, DFS Series, Low-Capacity) was used to quantify isometric cervical extension, flexion, and right and left lateral flexion strength. Participants were seated in a selectorized Pro 4-way neck training machine with arms crossed over their chest and stabilized at the waist with a Velcro strap. A stationary chair was used to position subjects' legs at approximately 90^0 of hip flexion with full knee extension. The force gauge was secured to the distal end of the machine's steel cable just above the weight stack attachment site with the pin placed in the bottom stack to prevent movement (see Figure 1). Head pad positioning for isometric cervical strength measurements was just above the occipital protuberance for extension, in the center of the forehead for flexion, and on the inferior portion of the parietal bone, just superior of the temporal bone and in alignment with the ear for right and left lateral flexion. Subjects were instructed to apply maximal force against the pad for 3 s and three trials were performed with a 1-min rest period between attempts. Testing sequence was extension, flexion, right lateral flexion and left lateral flexion. The peak force was recorded for each trial and the average of the three trials was reported.

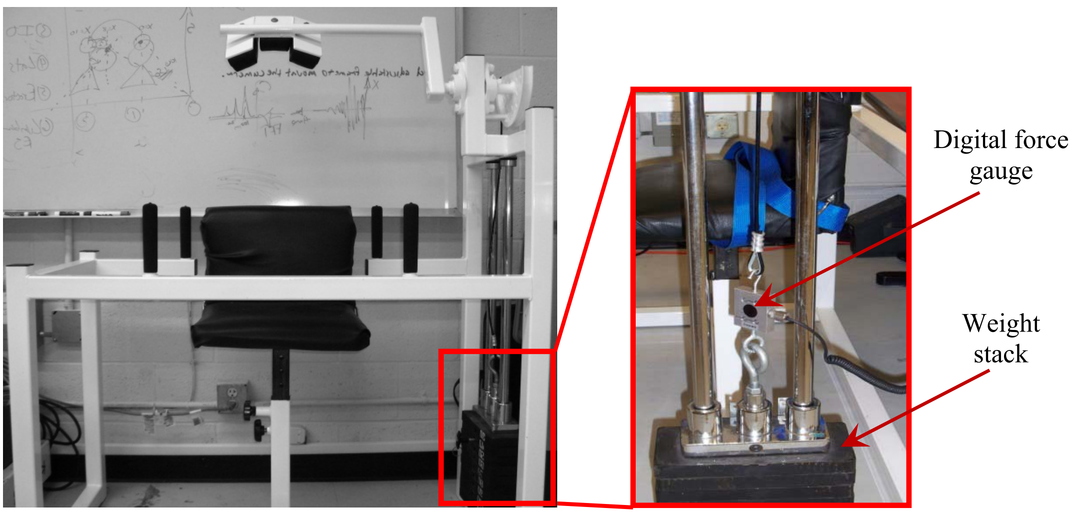

Figure 1: Force gauge attachment to selectorized pro 4-way neck machine.

Kinematic and EMG analyses during Tackling.

At baseline, subjects completed a minimum of two tackling practice sessions consisting of at least five tackles per session. A standard padded tackling dummy (56.36 kg, 60 in tall) was positioned in front of two wrestling mats placed for subject safety (see Figure 2). A mark (48 in from the floor) was drawn on the dummy and designated as the desired contact point for each tackle. Prior to tackling, subjects watched a short tackling instructional video (Bullis & Journell, 2001) and were fitted for a football helmet (Air Advantage, Schutt Sport, Litchfield, IL). Tackling procedures entailed participants starting in a three-point football stance exactly five yards from the tackling dummy. Once set, participants were instructed to maximally accelerate and attempt to deliver maximal force upon impact with the dummy. They were also instructed to use a standardized tackling technique that included both preparation (prior to dummy contact) and execution phases (Bullis & Journell, 2001; Journell, 2004). Body positioning during the preparation phase consisted of the participants rising up on the balls of their feet with hips and knees flexed, back in extension, elbows flexed at 90^0 in a semi-supinated position, shoulders hyperextended, head and chest up, and neck bulled (extension of the cervical spine and scapular elevation). The execution phase body position included flexing the shoulders and wrapping of the arms around the dummy, chest up, ankles plantar-flexed, knees and hips extended, and both head and eyes in an up position (see Figure 3).

The EMG and kinematic responses to the football tackle were measured at baseline and within two weeks of the completion of the training program. A Noraxon Telemyo System (Noraxon USA., Inc., Scottsdale, AZ) was used to assess the EMG activity of the right and left SCM and UT muscles. Prior to tackling, the exact location of each motor point was determined using a low-voltage stimulator delivering a series of 5 ms pulses at a rate of 5 pulses/s.

The SCM mark was measured in cm distal from the mastoid process in line with the sternal head of the muscle. The UT mark was placed in relation to an imaginary lead line between the C7 spinous process and the posterolateral aspect of the acromion. The motor point was measured with a metric tape and recorded as the number of cm lateral from the C7 vertebrae and superior or inferior of this line. The recorded motor point locations were used for post-training testing. Following motor point identification and recording, the skin surface distal to each site was shaved, rubbed with a disposable, light abrasive paper, and cleaned with 70% alcohol. Disposable Ag/AgCl dual self-adhesive snap Noraxon electrodes (spacing – 2.0 cm) were placed immediately distal to each motor point and parallel with the underlying muscle fibers.

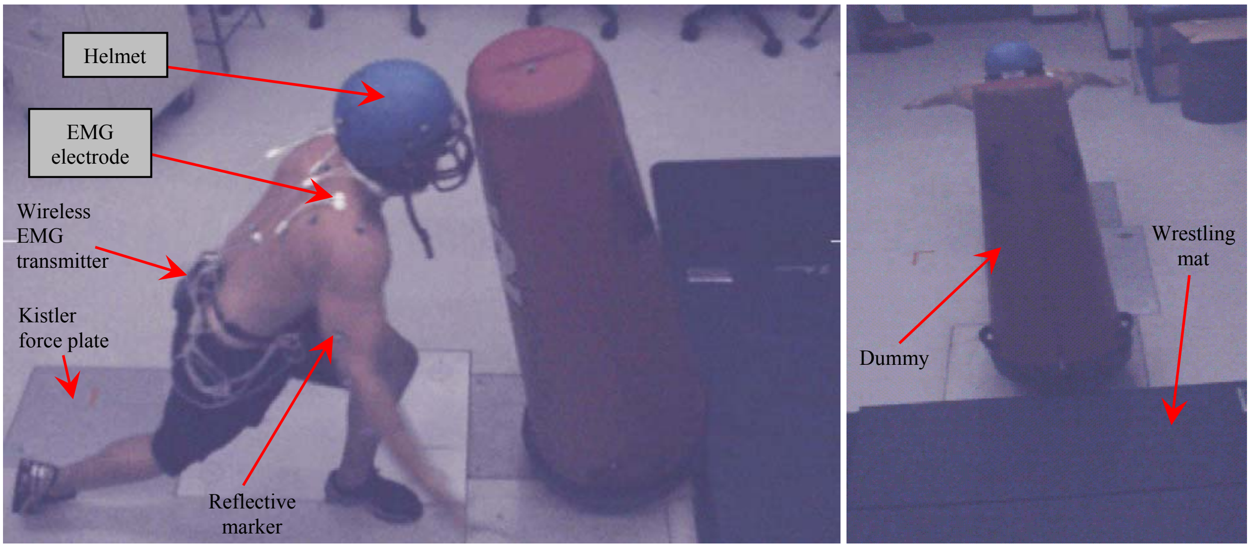

Figure 2. Football tackling motion capturing setup.

EMG signals were sampled at a speed of 2400 Hz using a 16-bit A/D converter and rectified by a full-wave active rectifier with zero threshold, then low-pass filtered, d.c. – 100 Hz. Each electrode-amplifier output was electrically isolated, amplified, and low pass filtered. EMG data collection was synchronized with the motion analysis system. Data were used to determine peak muscle amplitude of the SCM and UT between the time of initial contact with the tackling dummy and cessation of the subject's head backward displacement in the X-axis (sagittal plane) The root mean square (rmsEMG) of the signal for each trial was normalized to the middle-second rmsEMG value obtained during a 3 seconds maximal voluntary contraction (MVC) of an exercise used to target each muscle (flexion – SCM, extension – UT). Isometric MVCs for normalization purposes were performed during both pre- and post-training test sessions and followed the same procedure as performed in the isometric strength assessment.

A ViconNexus® Motion Capturing System (Oxford Metrics, United Kingdom) was used to gather three-dimensional kinematic data. All trials were recorded with 10 MX infrared cameras providing 1024 x 1024 pixel resolution and collected at 120 Hz (see Figure 4). Following EMG preparation and normalization procedures, 23 reflective markers were placed with double-sided adhesive tape to the subject's upper extremity segments and joints. Markers were placed on the right and left anterior aspect of the football helmet, right and left posterior aspect of the football helmet, C7 spinous process, right and left acromion processes, right scapula at the approximate level of the T4 spinous process, sternal notch, xiphoid process, inferior one-third of the lateral right humerus, superior one-third of the lateral left humerus, T10 spinous process, lateral epicondyles of the right and left humerus, distal one-third of the lateral right and left forearms, radial and ulnar styloid processes of the right and left wrists, and dorsal aspect of the right and left hands between the 2nd and 3rd metacarpals.

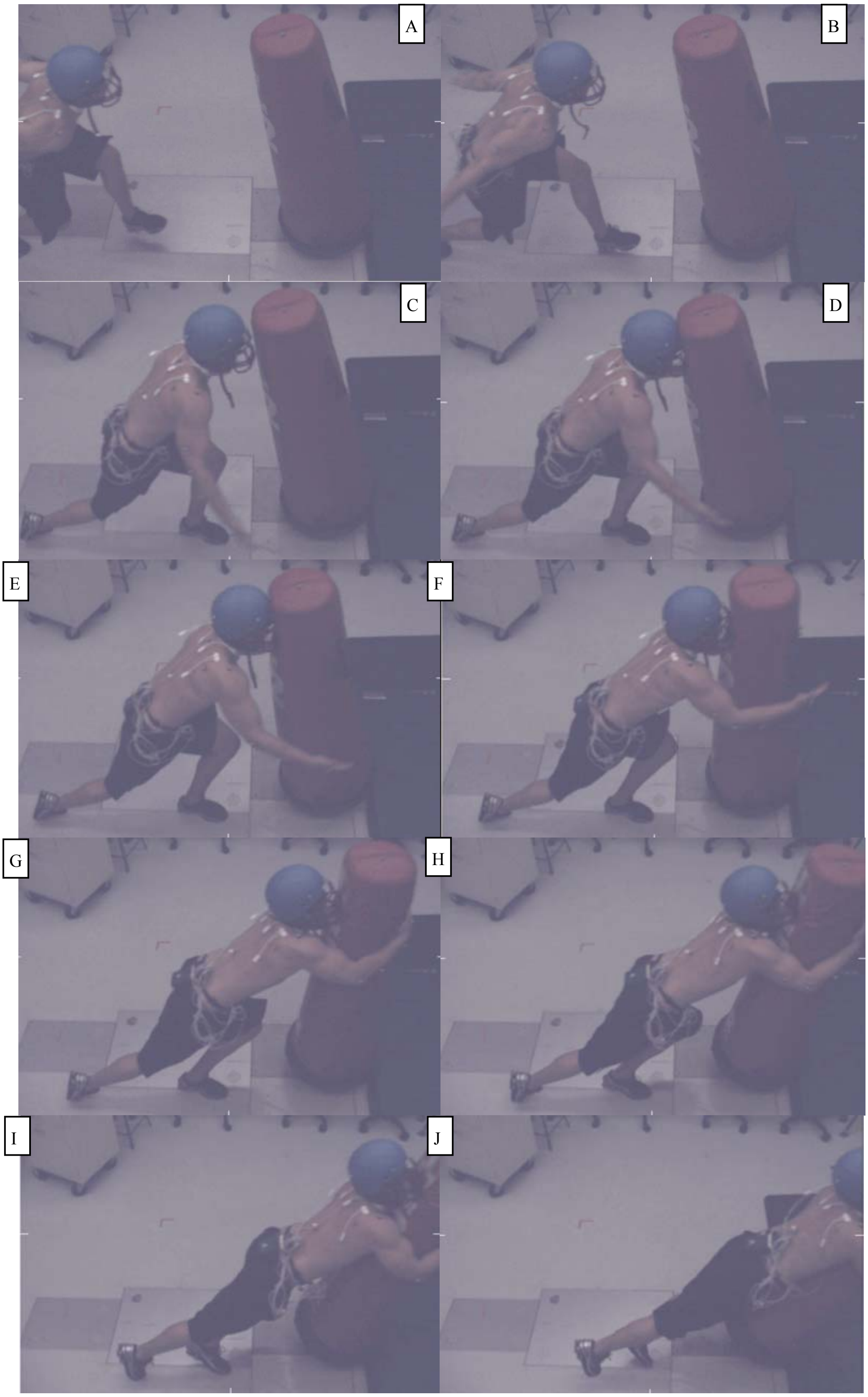

Figure 3. Football tackling motion capturing.

Before tackling, subjects performed a static trial by standing immobile in the center of the capture area while data were recorded. All markers were manually labeled so subsequent tackling trials could be labeled automatically. Subjects then set themselves in their three-point football stance and upon verbal cue from the investigators, accelerated toward and tackled the dummy as instructed during familiarization. Five tackles were performed following the mechanics outlined above with a minimum of 3 min of rest between tackles.

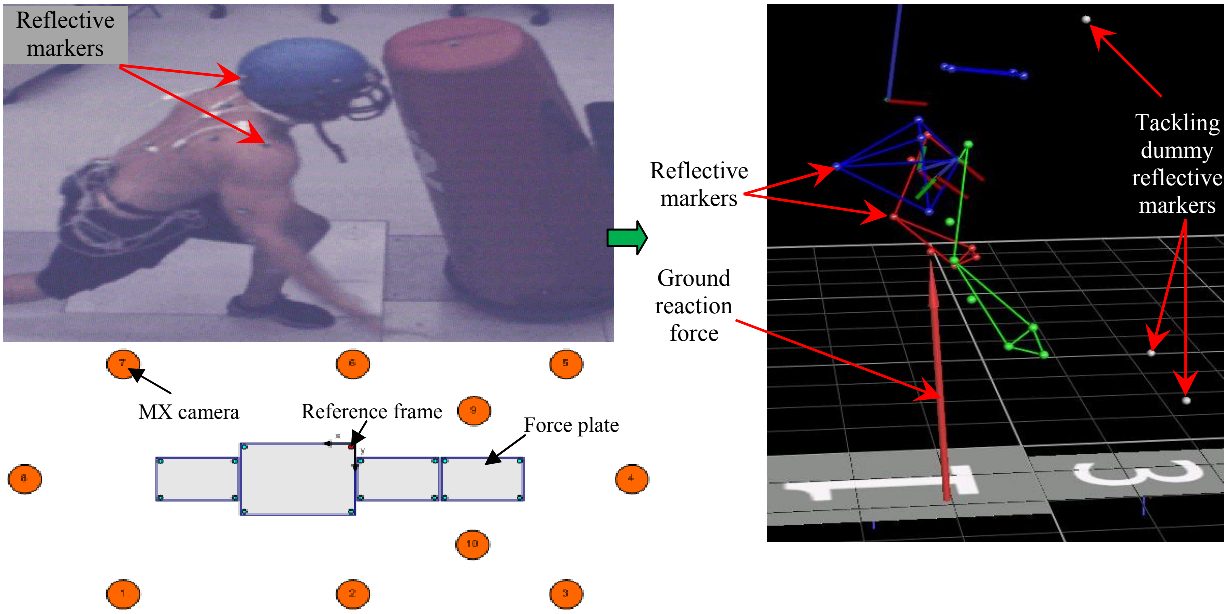

Figure 4. Data collection setup and the developed biomechanical model.

Data collected with this system were used to determine peak linear and angular head acceleration, head-cervical segment angular displacement, and time to peak acceleration values. Head-cervical segment angular displacement was calculated from the time that contact was made with the tackling dummy until motion (extension) in the sagittal plane ceased. Both peak head-cervical angular acceleration and head linear acceleration were calculated as the greatest acceleration within each displacement trial.

2.5. Statistical Analysis

Data are presented as means ± SD. The SPSS for Windows, Version 17.0, statistical program (SPSS, Inc., Chicago, IL) was used for data analyses. The significance of mean differences in neck girth and cervical strength before and after training was assessed with paired-samples *t*-tests. The significance of within- and between-condition mean differences in normalized rmsEMG and kinematic data was assessed by ANCOVA, with repeated measures and followed by post hoc analysis using the Bonferroni Test. Covariates for EMG and kinematic analyses were linear acceleration and average pre- and post-training approach speed, respectively. The significance of within- and between-condition mean differences in absolute rmsEMG activity was assessed by ANOVA, with repeated measures and followed by post hoc analysis using the Bonferroni Method. Statistical significance was set at $p \leq 0.05$.

3. Results

Anthropometric, strength, and kinematic data were recorded for 16 subjects before and after an eight-week cervical resistance training program. EMG data was captured on a subset of six subjects.

3.1. Anthropometric and Isometric Cervical Strength Assessment

Table 2. Isometric Cervical Strength and Neck Girth

Variable	Pre-training	Post-training	Significance
Extension strength, kg	73.64 ± 15.94	78.81 ± 13.97	*
Flexion strength, kg	40.42 ± 9.59	41.62 ± 9.55	
Right lateral flexion strength, kg	25.70 ± 8.18	27.60 ± 8.23	
Left lateral flexion strength, kg	25.49 ± 6.13	27.92 ± 8.23	*
Neck girth, cm	40.88 ± 2.04	41.12 ± 1.91	

Values are means ± SD; N = 16. * significantly different than pre-training. $p < 0.05$.

As shown in Table 2, although all cervical isometric strength measurements tended to increase with training, only the 7 and 10% increases in extension and left lateral flexion were found to be statistically significant (73.64 – 78.81 kg, $p = 0.004$; 25.49 – 27.92 kg, $p = 0.033$). No significant difference was noted for neck girth.

3.2. Kinematic Data

Analysis of pre- and post-training data revealed no statistically significant training effect for any kinematic variable (see Table 3). Specifically, there were no significant main or interaction effects for session or trial for peak linear or angular head acceleration, head-cervical segment angular displacement, or time to peak angular acceleration with average approach speed as a covariate (*p* values ranging from 0.051 to 0.986).

Table 3. Kinematic Responses during the Impact Phase of Tackling

Variable	Pre-training	Post-training
Peak linear head acceleration, *g*	7.23 ± 1.58	7.59 ± 2.06
Peak angular head acceleration, rad/s^2	431.96 ± 117.20	452.37 ± 127.16
Head-cervical segment angular displacement, ^{0}	12.14 ± 4.37	14.31 ± 5.25
Time to peak angular acceleration, ms	25.01 ± 11.63	28.63 ± 12.35

Values are means ± SD; n = 16. *g*, times the force of gravity; rad/s^2, radians per second squared; °, degrees; ms, milliseconds.

3.3. EMG Data

Electromyography data were normalized to the EMG values recorded during the MVCs producing the highest isometric force during pre- and post-testing. However, due to the significantly higher activity level of the UT during the dynamics of football tackling in comparison to the cervical extension MVC test, absolute measurements for both the SCM and UT were used for specific within-session muscle utilization comparisons. Analysis of pre- and post-training data revealed no effect of training for any normalized rmsEMG variable. Specifically, there were no significant main or interaction effects for muscle, session, or trial for normalized rmsEMG activity with average linear head acceleration as a covariate (*p* values ranging from 0.590 to 0.998). The observed power for the main effect of session was .056.

For absolute rmsEMG activity of the SCM and UT, there was a statistically significant main effect for muscle ($p < 0.001$) but not for session ($p = 0.181$) (see Figure 5). A statistically significant interaction between muscle and session ($p = 0.014$) was found for absolute rmsEMG activity. At both pre- and post-training sessions, right UT rmsEMG activity was greater than that of the right ($p = 0.021$) and left ($p = 0.007$) SCM while left UT rmsEMG activity was greater than that of the left SCM ($p = 0.031$). No significant differences were noted between right and left UT or right and left SCM rmsEMG activity.

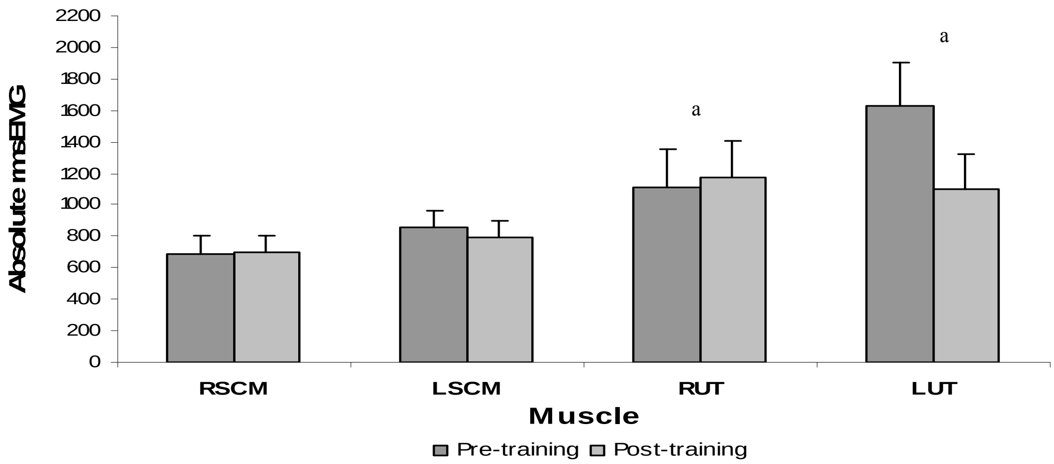

Figure 5. Group means for SCM and UT absolute rmsEMG. [a] Indicates differences between UT and SCM absolute rmsEMG within pre- and post-training test sessions ($p < 0.05$).

4. Discussion

The purpose of this study was to measure the effects of an eight-week isoinertial cervical strength training program on the EMG of the neck muscles and kinematic responses of the head and neck to a football tackle. The primary finding of this study was that despite modest training-induced improvements in isometric cervical extension and left lateral flexion strength, the training program under the current experimental procedures had no influence on the EMG or kinematic responses during a standardized football tackle. The SCM and UT have been presented as the primary dynamic stabilizers of the head and neck and likely play a critical role in the prevention of concussive injuries (Cantu, 2000; Cross & Serenelli, 2003; Tierney et al., 2005). Specifically, their cross-sectional area, strength, contractile onset time and velocity, and synergistic cocontraction may largely determine the degree of linear and angular head acceleration and their ability to absorb the energy upon direct or indirect impact. The inability of the current training program to affect many of these variables along with training recommendations are discussed below.

4.1. Isometric Cervical Strength and Neck Girth

The limited training-induced improvements in isometric cervical strength and neck girth during the current study (Table 2) are similar to results reported in earlier studies (Mansell et al., 2005). The reason for these modest increases in isometric strength is likely due to the low intensities used during training. Those that have found more profound training-induced increases in isometric cervical strength and neck girth (Conley et al., 1997; Maeda et al., 1994; Taylor et al., 2006) have followed training regimens with similar frequency, duration, and progression, but greater intensity (100% of 10RM). Due to the conservative initial starting weight of the current study (60% of 10RM), the training intensity at the end of the current study was still 25% less than the initial load utilized by the researchers who reported greater improvements in isometric cervical strength and neck girth. A positive linear relationship has been shown to exist between joint resistance to movement and the cross-sectional areas of the muscles affecting that joint (Chleboun et al., 1997). Since the correlation between muscle size and active contractile strength is widely accepted (Chleboun et al., 1997; Kawakami et al., 1994), it is reasonable to propose that the lack of kinematic changes following cervical resistance training in the current study is directly related to the lack of significant increases seen in two of the four assessed strength measurements and neck girth. This suggests that greater emphasis be placed on higher volume and intensity training of the neck. However, the efficacy of such training programs on improving head and neck stabilization during a standard football tackle is currently unknown.

4.2. Contractile Velocity

The current study is the first to our knowledge to examine the effects of cervical strength training on the EMG of neck musculature and the kinematic responses of the head and neck during a dynamic task that closely simulates a sports activity. The only comparable work was performed by Mansell et al. (2005) who tested the effects of cervical resistance training on head-neck dynamic stabilization in collegiate soccer players. Utilizing slow isoinertial training techniques similar to those used in the current study, they found no EMG (UT and SCM) or kinematic changes when subjects' heads were forced into extension and flexion by dropping a 1-kg weight attached to a pulley system a distance of 15 cm. These limited results do raise the question of whether training speed during cervical resistance training may be a major factor affecting the degree of dynamic stabilization during sporting activities. The isoinertial training program in the current study was chosen due to its acceptance as the most common method for training cervical musculature in football players even though currently no post-training injury reduction data has substantiated its use (Bland, 1996; Cramer, 1999; Cross & Serenelli, 2003). However, due to the high-speed movement of the head upon impact during a football tackle, training specificity would suggest that high-speed isoinertial or plyometric training, which feature greater emphasis on contractile velocity, may be more beneficial than slow isoinertial training in improving dynamic stabilization of the head and neck.

4.3. Firing Patterns of UT and SCM

The UT exhibited higher EMG activity than the SCM in response to a football tackle (Figure 5). This may be explained by the role of the UT both before (preparation phase) and after impact as is works synergistically with the SCM in providing dynamic stabilization to the head and neck. Body positioning in preparation for a tackle includes shoulder hyperextension, scapular elevation, and cervical spine extension.

The latter two are actions of the UT and create a bulling of the neck, allowing the tackler to maintain a head-up and eyes-up position which increases joint stiffness and stability and aids in the prevention of cervical spine injury (Bullis & Journell, 2001; Journell, 2004; Kaneko et al., 1983). Recent work has suggested these roles for the UT in preparation for a rugby tackle, though EMG data collection was limited to other scapulohumeral musculature (Herrington & Horsley, 2009).

Previous work analyzing soccer heading has demonstrated the synergistic activity of the SCM and UT prior to and after ball contact (Bauer et al., 2001). The SCM showed earlier and higher activity prior to ball contact while UT activity was longer and peaked following impact. Explanations included the role of the SCM in acceleration of the head toward the ball and the role of the UT in head deceleration following contact with the ball. While our EMG analysis did not assess onset time or activity cessation order, the high UT involvement is in agreement with previous work (Bauer et al., 2001). Although interpretation of these findings may be limited due to raw EMG analysis, results suggest the importance of the UT in providing both preparatory and post impact head and neck stabilization during a football tackle.

4.4. Limitations

Accepted limitations of this study include both the low range of head accelerations that resulted from impact with the tackling dummy and the standardized tackling mechanics that were employed. The average peak pre- and post-training linear head accelerations in the current study of 7.23 and 7.59 *g* (Table 3) were significantly less than the average ranges found in both high school (23-25 *g*) (Broglio et al., 2009) and collegiate (21-32 *g*) (Brolinson et al., 2006; Duma et al., 2005; Guskiewicz et al., 2007; Mihalik et al., 2007) football players during actual practice and game play. Likewise, our mean head-neck angular accelerations for pre- (431.96 rad/s^2) and post-training (452.37 rad/s^2) were significantly less than those during high school (1669.79 rad/s^2) (Broglio et al., 2009) and collegiate (2020 rad/s^2)) (Brolinson et al., 2006; Guskiewicz et al., 2007) play. Due to the low range of head accelerations found in pre- and post-training testing and the non-significant effect of the training program, it is reasonable to suggest that dynamic stabilization of the head and neck could have been easily accomplished by the inherent tensile and muscular strength of the SCM and UT. Resultant forces and head accelerations upon dummy impact were thus not great enough to elicit an increased myoelectrical demand.

It is important to note that initiating contact with the helmet and/or facemask during tackling is a significant safety concern and is prohibited at all levels of football play. However, under the current experimental conditions, it was necessary to include helmet and facemask contact as part of participants' initial impact with the dummy. This contact elicited the backward displacement of the head and cervical segment which was the basis for our assessment of the effectiveness of the cervical resistance training program on increasing the dynamic stabilization of the head and neck during football tackling.

5. Conclusion

Under the current experimental conditions, the eight-week cervical resistance training program had no effect on the EMG activity of the neck musculature and kinematics of the head and neck in response to a football tackle. Although the slow isoinertial training program was sufficient to result in modest improvements in isometric cervical extension and left lateral flexion strength, the lack of emphasis on hypertrophy, contractile velocity, or cocontraction of the SCM and UT may have prevented it from improving head and neck stabilization during the football tackle. This is clinically relevant given the fact that isoinertial cervical resistance training on a four-way neck machine has been recommended as a means of reducing the incidence and severity of concussions among football players (Bland, 1996; Cramer, 1999; Cross & Serenelli, 2003). Future research should examine whether the goal of cervical resistance training to reduce the risk of concussions in football should be centered on muscle hypertrophy obtained through slow speed load-intensive isoinertial training with particular emphasis on the UT, or higher velocity training (high-speed isoinertial and/or plyometric).

6. References

[1] Bailes JE, Cantu RC. Head injury in athletes. *Neurosurgery*. 2001, **48**: 26-45; discussion 45-6.

[2] Bauer TA, Thomas TS, Cauraugh JH, Kaminski TW, Hass CJ. Impact forces and neck muscle activity in heading by collegiate female soccer players. *J Sports Sci.* 2001, **19**: 171-179.

[3] Bland JH. Helping athletes avoid neck injuries. *J Musculoskel Med.* 1996, **13**: 30-38.

[4] Broglio SP, Sosnoff JJ, Shin S, He X, Alcaraz C, Zimmerman J. Head impacts during high school football: A

biomechanical assessment. *J. Athl Train.* 2009, **44**: 342-349.

[5] Brolinson PG, Manoogian S, McNeely D, Goforth M, Greenwald R, Duma S. Analysis of linear head accelerations from collegiate football impacts. *Curr. Sports Med. Rep.* 2006, **5**: 23-28.

[6] Bullis K, Journell TW. Fundamentals of Tackling, Coaching Science Video. (2001).

[7] Cantu RC. *in Neurologic Athletic Head and Spine Injuries* (W.B. Saunders, Philadelphia, PA, 2000).

[8] Chleboun GS, Howell JN, Conatser RR, Giesey JJ. The relationship between elbow flexor volume and angular stiffness at the elbow. *Clin. Biomech.* 1997, **12**: 383-392.

[9] Conley MS, Stone MH, Nimmons M, Dudley GA. Specificity of resistance training responses in neck muscle size and strength. *Eur. J. Appl. Physiol. Occup. Physiol.* 1997, **75**: 443-448 (1997).

[10] Cramer CR. A reconditioning program to lower the recurrence rate of brachial plexus neurapraxia in collegiate football players. *J. Athl Train.* 1999, **34**: 390-396.

[11] Cross KM, Serenelli C. Training and equipment to prevent athletic head and neck injuries. *Clin. Sports Med.* 2003, **22**: 639-667.

[12] Duma SM, Manoogian SJ, Bussone WR, Brolinson PG, Goforth MW, Donnenwerth JJ, Greenwald RM, Chu JJ, Crisco JJ. Analysis of real-time head accelerations in collegiate football players. *Clin. J. Sport Med.* 2005, **15**: 3-8.

[13] Guskiewicz KM, Marshall SW, Bailes J, McCrea M, Cantu RC, Randolph C, Jordan BD. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. *Neurosurgery***.** 2005, 57: 719-26; discussion 719-26.

[14] Guskiewicz KM, Marshall SW, Bailes J, McCrea M, Harding HP, Matthews A, Mihalik JR, Cantu RC. Recurrent concussion and risk of depression in retired professional football players. *Med. Sci. Sports Exerc.* 2007, **39**: 903-909.

[15] Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, Onate JA, Kelly JP. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study.*JAMA* 2003, 290: 2549-2555.

[16] Guskiewicz KM, Mihalik JP, Shankar V, Marshall SW, Crowell DH, Oliaro SM, Ciocca MF, Hooker DN. Measurement of head impacts in collegiate football players: Relationship between head impact biomechanics and acute clinical outcome after concussion. *Neurosurgery.* 2007, **61**: 1244-1251.

[17] Herrington L, Horsley I. Electromyographic analysis of selected shoulder muscles during a rugby football tackle. *Sports Medicine, Arthroscopy, Rehabilitation, Therapy and Technology.* 2009, 1.

[18] Journell TW. *in Biomedical Engineering Principles in Sports* (eds Hung, G. K. & Pallis, J. M.) New York, NY: Kluwer Academic / Plenum Publishers. 2004, pp. 321-331.

[19] Kaneko M, Fuchimoto T, Toji H, Suel K. Training effect of different loads on the force-velocity relationship and mechanical power output in human muscle. *Scand. J. Sport Sci.* 1983, **5**: 50-55.

[20] Kawakami Y, Nakazawa K, Fujimoto T. Specific tension of elbow flexor and extensor muscles based on magnetic resonance imaging. *Eur. J. Appl. Physiol.* 1994, **68**: 139-147.

[21] Maeda A, Nakashima T, Shibayama H. Effect of training on the strength of cervical muscle. *Ann. Physiol. Anthropol.* 1994, **13**: 59-67.

[22] Mansell J, Tierney RT, Sitler MR, Swanik KA, Stearne D. Resistance training and head-neck segment dynamic stabilization in male and female collegiate soccer players. *J. Athl Train.* 2005, **40**: 310-319.

[23] McCrory P, Johnston KM, Mohtadi NG, Meeuwisse W. Evidence-based review of sport-related concussion: basic science. *Clin. J. Sport Med.* 2001, **11**:160-165..

[24] Mihalik JR, Bell DR, Marshall SW, Guskiewicz KM. Measurement of head impacts in collegiate football players: An investigation of positional and event-type differences. *Neurosurgery.* 2007, **61**: 1229-1235.

[25] Naunheim RS, Standeven J, Richter C, Lewis LM. Comparison of impact data in hockey, football, and soccer. *J. Trauma.* 2000, 48: 938-941.

[26] Pellman EJ, Viano DC, Tucker AM, Casson IR, Waeckerle JF. Concussion in professional football: reconstruction of game impacts and injuries. *Neurosurgery.* 2003, **53**: 799-812; discussion 812-4.

[27] Viano DC, Casson IR, Pellman EJ. Concussion in professional football: biomechanics of the struck player—part. *Neurosurgery***.** 2007, **61**: 313-27; discussion 327-8.

[28] Taylor MK, Hodgdon JA, Griswold L, Miller A, Roberts DE, Escamilla RF. Cervical resistance training: effects on isometric and dynamic strength. *Aviat. Space Environ. Med.* 2006, **77**: 1131-1135.

[29] Tierney RT, Sitler MR, Swanik CB, Swanik KA, Higgins M, Torg J. Gender differences in head-neck segment dynamic stabilization during head acceleration. *Med. Sci. Sports Exerc.* 2005, **37**: 272-279.

[30] Viano DC, Casson IR, Pellman EJ. Concussion in professional football: biomechanics of the struck player—part. *Neurosurgery.* 2007, **61**: 313-27; discussion 327-8.