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Slow Isoinertial Cervical Strength Training Does Not Alter Dynamic Stabilization of the Head and Neck During a Standard Football Tackle

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SLOW ISOINERTIAL CERVICAL STRENGTH TRAINING DOES NOT ALTER
DYNAMIC STABILIZATION OF THE HEAD AND NECK DURING A STANDARD
FOOTBALL TACKLE

By

Peter J. Lisman

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
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FOOTBALL TACKLE

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The sternocleidomastoid (SCM) and upper trapezius (UT) muscles are the primary dynamic stabilizers of the head and neck and likely attenuate head acceleration with direct and indirect impacts. Increasing the strength of the SCM and UT through cervical resistance training has been recommended to prevent concussions in football players. The purpose of this study was to examine the effects of an eight-week isoinertial cervical resistance training program on SCM and UT muscle activity (EMG) and kinematic responses of the head and neck during a standard football tackle in college-aged males. Sixteen college-aged males (21.6 ± 2.8 y, 94.6 ± 13.3 kg) with previous high school football or rugby playing experience completed an eight-week isoinertial cervical resistance training program consisting of three sets of 10 repetitions of neck extension, flexion, right and left lateral flexion at 60-80% of 10 repetition maximum two to three times a week. Isometric cervical strength, neck girth, EMG, and kinematic responses of the head and neck during a standard football tackle were measured before and after training. All kinematic data were gathered using a three-dimensional motion capturing system. Training resulted in 7 and 10% increases in isometric cervical extension and left lateral flexion strength, respectively, but no changes were seen in isometric flexion or right lateral flexion strength or neck girth. Additionally, training had no influence on the

EMG responses of the SCM or UT, peak linear (7.23 vs. 7.59 g, $p = 0.115$; pre- vs. post-training) or angular (431.96 vs. 452.37 rad/s^2, $p = 0.864$) head accelerations during the standard football tackle. The UT demonstrated approximately 40% higher absolute EMG activity than the SCM during tackling both before and after training. Under the current experimental conditions, despite modest increases in isometric cervical extension and left lateral flexion strength, the eight-week isoinertial cervical resistance training program failed to augment dynamic stabilization of the head and neck during a standard football tackle in college-aged males. Future research should examine the effects of both slow speed load-intensive and high speed low-to-moderate load intensity isoinertial training as well as plyometric training in decreasing head acceleration during football tackling for injury prevention purposes.

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Chapter 1: Introduction

Up to 1.5 million people suffer brain injuries in the United States each year and 75% of these injuries are mild traumatic brain injuries or concussions.[1] Approximately 300,000 sports-related concussions occur per year in the United States with the highest percentage occurring in the sport of football.[2] It is estimated that between 3 and 25% of high school and college football athletes sustain concussions each year;[3-5] however, these reports likely underestimate the true concussion incidence rate due to non-reporting of concussions often caused by the failure to recognize symptoms or the fear of being removed from competition. 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. 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.[6] 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.[7, 8] 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.[9, 10] Both early reports[11] and more recent studies utilizing helmets instrumented with linear

accelerometers (Head Impact Telemetry System)[1, 5, 12, 13] agree that average linear head acceleration associated with football play ranges between 21-32 *g*. These average linear accelerations are similar to those seen during hockey checking (35 *g*) and while heading a ball in soccer (55 *g*).[11] Concussion-inducing impacts in Division I collegiate football players have been measured to range from 56-169 *g*[1, 5, 12, 13] which often exceeds the injury threshold of 70-75 *g* accepted by some researchers.[14, 15] While the incidence of concussions is integrally related to the degree of linear head acceleration, some do not agree that an injury threshold can be applied to predict injury. Mihalik et al.[12] reported that less than 1% of their 1,858 recorded impacts above 80 *g* resulted in concussion.

The sternocleidomastoid (SCM) and upper trapezius (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.[16-18] 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.[19] 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.[20] The applicability of this

study to field performance may be limited, however, due to use of external force application rather than soccer-specific activities such as heading. 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.

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 kinematics of the head and neck in response to a standard football tackle in college-aged males. It was hypothesized that the training program would result in increased EMG responses of the SCM and UT, as well as a reduction in head movement and acceleration following impact during a standard football tackle.

Chapter 2: Methods

Subjects

Sixteen college-aged men (21.6 ± 2.8 yr, 182.5 ± 6.0 cm, 94.6 ± 13.3 kg) were recruited from the University of Miami campus area using posted flyers. Fifteen subjects had high school football playing experience, while one subject had high school rugby playing experience. 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. The procedures and risks were thoroughly explained to the subjects and their written, informed consent was obtained. The University of Miami's Institutional Review Board approved the study.

Experimental Design

After screening, the EMG and kinematic responses to a standard 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,

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and kinematic measurements of peak linear head acceleration and head-cervical angular displacement, peak acceleration, and time to peak acceleration.

Anthropometric and Isometric Cervical Strength Assessment

Participant height, weight, neck girth, and isometric cervical strength were assessed at baseline and within two weeks of completion of the cervical resistance training program. Neck girth was measured using a metric tape measure while the participant was seated and with his gaze fixed on an object at eye level. The measurement was taken just superior of the thyroid cartilage. 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). Isometric cervical extension strength was evaluated with the head pad positioned just above the occipital protuberance. Isometric cervical flexion strength was assessed with the head pad positioned in the center of the forehead. Isometric right and left lateral flexion strengths

were assessed with the pad placed on the inferior portion of the parietal bone, just superior of the temporal bone and in alignment with the ear. 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. The 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.

Tackling Familiarization

At baseline, subjects completed a minimum of two tackling practice sessions consisting of at least five tackles per session. A standard padded pop-up tackling dummy (56.36 kg, 60 in tall) was positioned in front of two wrestling mats (5 x 10 ft, 2 in thick) placed for subject safety. A mark (46 in from 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[21] and were fitted for a football helmet (Air Advantage, Schutt) by the lead investigator. Tackling procedures entailed subjects starting in a three-point football stance exactly five yards from the tackling dummy. Once set, subject were instructed to maximally accelerate and attempt to deliver maximal force upon impact with the dummy. They were also instructed to use standardized tackling techniques that included both preparation (prior to dummy contact) and execution phases.[21-23] Body positioning during the preparation phase consisted of the participant 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 head and eyes up, while initiating contact with the front of the helmet and facemask.

Testing Protocol

The EMG and kinematic responses to the standard football tackle were measured at baseline and within two weeks of the completion of the cervical resistance training program. A Noraxon Telemyo System (Noraxon USA., Inc., Scottsdale, Arizona) 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. Voltage was progressively reduced from approximately 50 V until only one point elicited a response and was marked as the motor point for that muscle. The SCM mark was measured in cm distal from the mastoid process in line with the sternal head of the muscle. Others have reported the midpoint between the mastoid process and sternal notch as the preferred location for greatest myoelectrical activity.[24, 25] For the UT, the mark was placed in relation to an imaginary lead line between the C7 spinous process and the posterolateral aspect of the acromion. Previous authors have identified the region of highest myoelectrical activity for the UT to be 2 cm lateral from the midpoint of this line.[26, 27] 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. Because raw EMG signals were recorded using a wireless EMG telemetry system transmitter worn around the subject's waist, the quality of the signals was visibly assessed for each muscle before data collection. Each electrode-amplifier had a gain of 725 with a common mode rejection ratio of 90 dB at 60 Hz and a second-order 10 Hz – 5 kHz band-pass filter. This signal was 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 (fourth-order filter at 2000 Hz). Signals were sampled at a speed of 2400 Hz using a 16-bit A/D converter and 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 s maximal voluntary contraction (MVC) for each muscle (flexion – SCM, extension – UT). Isometric MVCs for normalization purposes followed the same testing 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 cameras providing 1024 x 1024 pixel resolution and collected at 120 Hz (Figure 2).

Following EMG preparation and normalization procedures, 23 reflective markers were secured with double-sided adhesive tape to the subjects which allowed X, Y, and Z coordinates of the body segments to be recorded continuously. 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 styloid processes of the right and left wrists, and dorsal aspect of the right and left hands between the 2nd and 3rd metacarpals.

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.

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 contact point 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.

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. Subjects were permitted to continue their normal recreational resistance training regimens, but agreed not to perform either shoulder shrugs or upright rows throughout the eight-week program. 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-repetition maximum (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.

Statistics

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 Test. Statistical significance was set at $p \leq 0.05$.

Chapter 3: Results

Anthropometric, strength, and kinematic data were recorded for 16 subjects before and after an eight-week cervical resistance training program. While kinematic data were available for all subjects, complete EMG data were only captured for a subset of six subjects due to an EMG signal sampling speed error.

Anthropometric and Isometric Cervical Strength Assessment

Subject characteristics are displayed in Table 1. 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, $p = 0.033$; Table 2). No significant difference was noted for neck girth.

EMG Data

EMG 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 ($p < 0.01$) but not for session ($p = 0.181$) (Figure 3). A statistically significant interaction between muscle and session ($p < 0.05$) was found for absolute rmsEMG activity. At both pre- and post-training sessions, left UT rmsEMG activity was approximately 58 – 138% greater ($p < 0.05$) than that of the right SCM. No significant differences were noted between right and left UT or right and left SCM rmsEMG activity.

Kinematic Data

Due to some difficulties associated with lack of reflective marker visibility during tackling and ensuing motion analysis data processing, kinematic data from only four of five tackles were used for pre- and post-training analyses. When all five tackling trials could be processed, the four tackles with approach speeds nearest to the mean were used. Analysis of pre- and post-training data revealed no statistically significant training effect for any kinematic variable (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).

Chapter 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 standard football tackle in college-aged males. The primary findings of this study were 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 standard 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.[9, 17, 18] 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.[28-33] The inability of the current training program to affect many of these variables along with training recommendations are discussed below.

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.[20] reported a 20% increase and 10% decrease in isometric cervical flexion and extension strength, respectively, with no significant increase in neck girth following a similar eight-week training program. Both studies involved a frequency of two to three training sessions per week with each session consisting of three sets of 10 repetitions for each cervical movement and initial training intensities ranging from 55-

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60% of 10RM that increased 5% every two weeks. The reason for these modest increases in isometric strength are likely due to the low intensities used during training. Those that have found more profound training-induced increases in isometric cervical strength (31-73%) and neck girth (4-13%) have followed training regimens with similar frequency (3 d/wk), duration (8 wk), and progression (5-10% every two wk), but greater intensity (100% of 10RM).[34-36] 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 those finding 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.[32] Since the correlation between muscle size and active contractile strength is widely accepted,[32, 37] it is reasonable to propose that the lack of increased dynamic stabilization with 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.

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.[20] 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.[17, 38, 39] 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. Isoinertial training at high speeds and low to moderate loads has been shown to be superior to traditional weight training in increasing both power and tests of athletic performance.[40, 41]

Firing Patterns of UT and SCM

The UT exhibited higher EMG activity than the SCM in response to a football tackle (Figure 3). 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.[21-23] 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.[42]

Previous work analyzing soccer heading has demonstrated the synergistic activity of the SCM and UT prior to and after ball contact.[43] 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.[43] 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.

Limitations

An accepted limitation of this study was the low range of head accelerations that resulted from impact with the tackling dummy. 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)[44] and collegiate (21-32 g)[1, 5, 12, 13] 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)[45] and collegiate (2020 r/s^2)[1, 5] play. Further, concussion-inducing linear head accelerations of 56-168.71 g[1, 5, 12, 13] have been reported in college football players while others have proposed an injury threshold of 70-75 g.[14, 15]

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.

Chapter 5: Summary and 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 standard 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.[17, 38, 39] 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).

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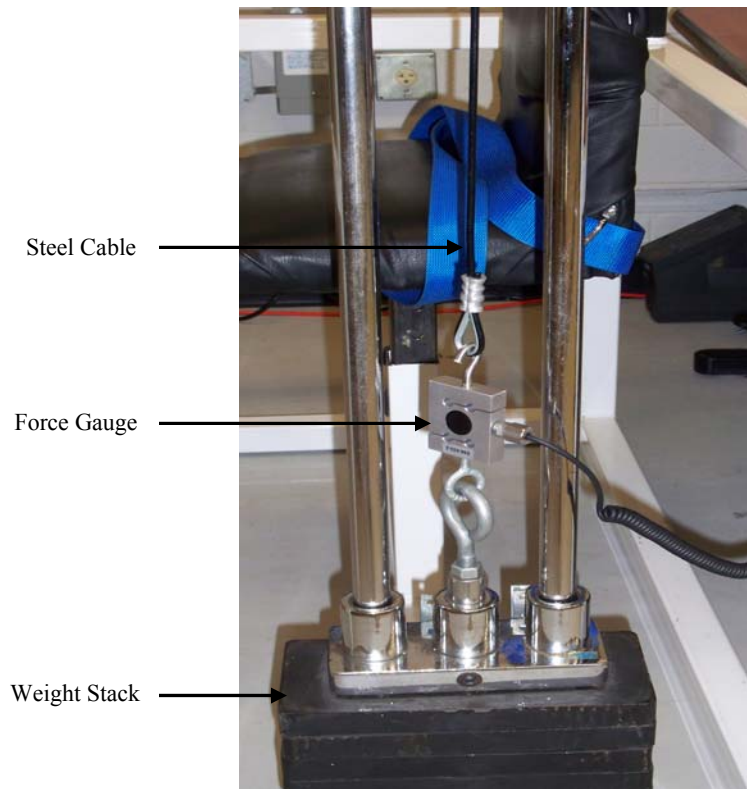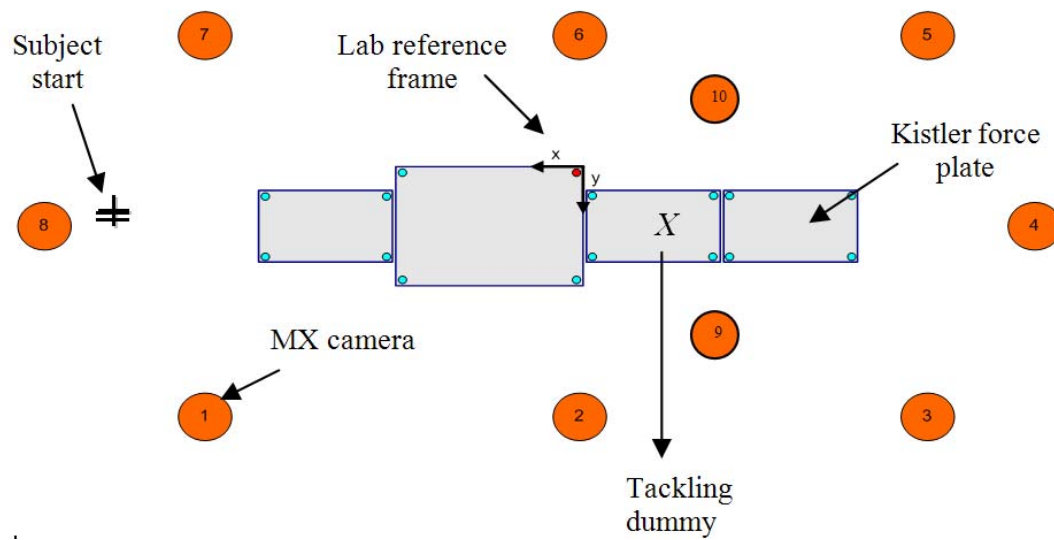Figure 1: Force gauge attachment to selectorized pro 4-way neck machine.

Steel Cable

Force Gauge

Weight Stack

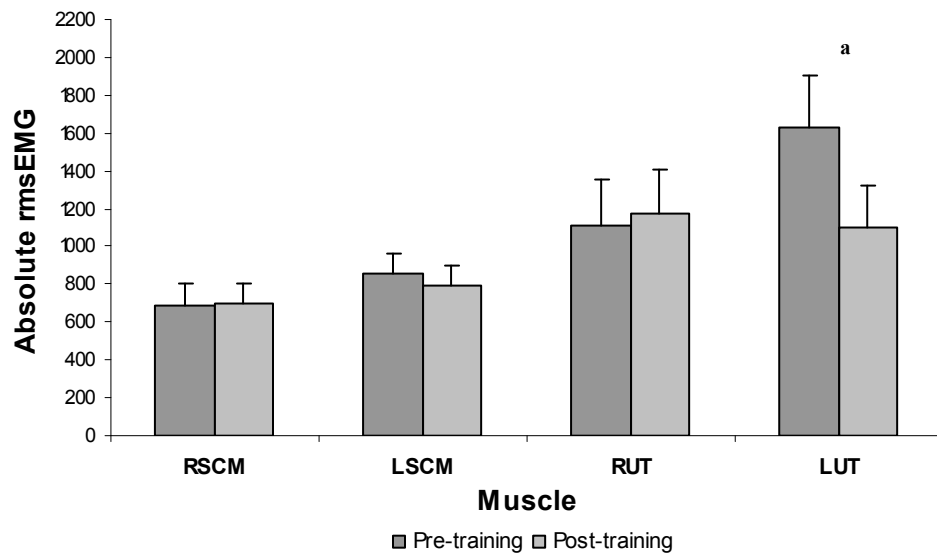Figure 2: Cameras and tackling dummy configurations.

Figure 3. Group means for SCM and UT absolute rmsEMG. [a] Indicates differences between left UT and right SCM absolute rmsEMG within pre- and post-training test sessions ($p < 0.05$).

Table 1. Physical Characteristics of Subjects

Variable	
Age, yr	21.6 ± 2.8
Height, cm	182.5 ± 6.0
Mass, kg	94.6 ± 13.3
Body mass index	28.4 ± 3.5
Head mass, kg [a]	7.8 ± 1.1

Values are means ± SD; n = 16. yr, years; cm, centimeters; kg, kilograms. [a] Head mass was estimated by multiplying a pre-determined head-neck segment value by the total body mass, based on recommendations by Plagenhoef.[45]

Table 2. Isometric Cervical Strength and Neck Girth

Variable	Pre-training	Post-training
Extension strength, kg	73.64 ± 15.94	78.81 ± 13.97[a]
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[a]
Neck girth, cm	40.88 ± 2.04	41.12 ± 1.91

Values are means ± SD; n = 16. [a] significantly different than pre-training. $p < 0.05$.

Table 3. Kinematic Responses to Standard Football Tackle

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.