EFFECTS OF PLYOMETRIC TRAINING ON CERVICAL MUSCLE STRENGTH, ACTIVATION, AND HEAD IMPACTS IN FEMALE HIGH SCHOOL SOCCER PLAYERS

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

Recent research has highlighted alarming rates of concussion incidence among female soccer athletes. Studies have demonstrated neck strength as a possible predisposition to concussive forces, but no research has incorporated a dynamic training program emphasizing neuromuscular control related to the cervical musculature. The objective of this study was to investigate the effects of a sport-specific plyometric and functional training program on cervical muscle strength, size, and activation, and subsequent head impacts. An experimental, between-groups design was utilized using high school athletic training and sports facilities. Eight high school female soccer players (age = 16.24 ± 1.07 years; height = 165.89 ± 10.95 cm; mass = 55.17 ± 7.09 kg) participated in the research. An 8 week plyometric and functional training program consisting of 3 sport-specific drills was implemented for the intervention group. The control group did not perform any additional cervical muscle strength training. Isometric cervical neck strength (lbf) was measured using a MicroFET 2 handheld dynamometer, neck girth (cm) was recorded using a standard metric tape measure, muscle activation (% maximum voluntary contraction of the sternocleidomastoid and upper trapezius muscles) was measured using a 16 channel wireless TeleMyo DTS EMG system, and head impact acceleration values (G) were recorded pre- and post-intervention by a DTS 3D 24G Accelerometer. Significant differences were identified between groups related to the mean peak head accelerations between the 3 axes of measurement. Additionally, differences in mean upper trapezius activation ($p < 0.001$), right sternocleidomastoid ($p = 0.002$), and left sternocleidomastoid ($p < 0.001$) muscles were identified over time. No significant group effects were discovered related to neck strength, neck girth, mean acceleration upon impact, or cervical muscle activation or duration throughout heading activities ($p \geq 0.05$). The plyometric intervention did not result in significant strength gains compared to the control group, but subjects did reveal a trend in strength gains over time. Functional plyometric training resulted in increased peak head accelerations within the intervention group. The results suggest that plyometric training resulted in greater neuromuscular control and heading force in soccer specific activities, but further research needs to be conducted as it relates to brain injury susceptibility.

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1. INTRODUCTION

Concussions and mild traumatic brain injuries (mTBI) are becoming increasingly prevalent throughout all arenas of sport competition, with potentially debilitating and life-altering effects resulting directly from brain injuries suffered through athletic participation.[1,2] Many studies have investigated potential causes of mTBI, yet there is no consensus on which predisposing factors are most important in limiting the external forces placed on the head-neck complex during competition,[3] particularly in terms of concussion incidence and severity related to gender differences.[4] Neck musculature is believed to play a role in the dispersal of potentially harmful forces placed on the skull,[5] but little research exists related to strength training specific to the cervical muscles. The goal of this study was to investigate the efficacy of a neck plyometric and functional training program in soccer players. Biomechanical characteristics and cervical neck strength have both been discussed as contributing to the incidence and severity of head impacts, particularly playing a role in the determination of acceleration values during contact.[5-7] Narrowing down potential predispositions of head impacts is important in the prevention and management of concussions in sport, and further research may provide health care professionals with a better understanding of the mechanisms and effects of concussive and sub-concussive impacts, specifically within an athletic population.

Recent research has highlighted alarming rates of concussion incidence among sport participants, especially soccer athletes.[1,8] Within soccer participation, head injury commonly occurs from the direct contact of an opponent's head or body, with blows to the side or temporal region of the skull resulting in the highest incidence of concussion.[9] In terms of specific mechanism of injury, heading the ball, or attempted headers, lead to 60.8% of head injuries during soccer activities.[10] Compared to male athletes of the same age and participation level, female soccer players sustain more concussions, present more symptoms, display larger neurocognitive deficits, and have greater symptom severity at identical stages of the injury and the recovery process.[4,11] Additionally, high school interscholastic sports present very high incidences of concussions and mTBI relative to the competition level. Of 20 common high school sports investigated, girls' soccer produced the second highest rate of documented concussions (behind only American football), with girls' concussion rates 1.9 times that of male soccer athletes.[10] The rates are especially concerning given the population's vulnerability due to their developing physical and neurological function. Head-neck strength and stabilization has been theorized to be a cause of this discrepancy, with the varying muscle characteristics between genders thought to contribute to the differences in external loads between players in the same sport and competition level.

Prior to, and during contact with the skull, cervical muscles tense, bracing and stabilizing the head and neck during movement to deflect external loads and limit accelerations and subsequent contact forces on the head when expecting or sustaining impacts.[6] The sternocleidomastoid (SCM) and trapezius muscles, in particular, serve as the primary stabilizers of the head and neck during dynamic movements. Given their influence on cervical flexion, extension, and lateral rotation, the SCM and trapezius muscles are directly related to the acceleration placed on the skull,[13,14] indicating a primary role in the determination of impact severity.

Previous studies [5-7] have investigated the role of cervical musculature in the determination of impact severity, particularly in soccer participation. Research has shown that a negative relationship exists between neck strength and impact measurements in female soccer players, with weaker neck musculature resulting in greater acceleration of the head.[7] Similarly, a discrepancy has been found between genders in dynamic stabilization, with female participants having lower levels of isometric strength and stiffness, but greater muscle activity and higher acceleration measurements.[5] In a similar follow-up study, an 8 week resistance training intervention was implemented in collegiate soccer players to further determine the usefulness of neck strength, size, and stiffness on estimating acceleration during dynamic loading. The isotonic and isometric program produced increases in strength and size, but no significant differences in dynamic stabilization compared to pretest values.[6] Athletes with weaker necks have also been found to sustain higher impact measurements during soccer specific heading activities,[15] with heading technique also a potential factor in acceleration magnitudes.[10]

Additionally related to neck musculature, muscle asymmetry has been theorized to account for increased acceleration values during soccer specific activities.[7] Strengthening programs have been previously implemented with the goal of altering predisposing muscle strength characteristics and asymmetries, and decreasing the subsequent acceleration measurements, but have primarily focused on isometric and isotonic strengthening.[6] Little to no research currently exists utilizing a plyometric, functional, sports specific protocol for strengthening the cervical musculature for the purpose of decreasing head impact magnitudes in soccer athletes. Limited research has been performed related specifically to dynamic strengthening, especially in a population of high concussion incidence such as high school soccer. Narrowing down potential predispositions of head impacts and identifying causes of epidemiological differences is important in the prevention and management of concussion in sport, and further research may provide health care professionals with a better understanding of the mechanisms and effects of mTBI within athletic participation.

Regarding this specific research study, it was hypothesized that a sports specific plyometric and functional training program would result in increases in cervical strength, a resulting decrease in quantified head impact severity, with an observable alteration in muscle activation patterns during loading.

2. METHODS

Research Design

An experimental, between-groups design was implemented, with female soccer players (ages 14-18), randomly separated into control and intervention groups. The independent variable of interest was the sport-specific plyometric and functional neck strengthening program. The intervention training protocol involved 3 separate heading activities: partner ball tosses for accuracy, partner ball tosses for distance, and ball tosses for speed. Dependent variables included the sternocleidomastoid (SCM) and trapezius muscle activation (%MVC), duration (s), cervical muscle strength (lbf), neck girth measurements (cm), and mean and peak acceleration measurements (G). Muscle activation patterns using electromyography (EMG) data were collected to determine peak muscle amplitude and muscle amplitude area (normalized to % of the subject's maximum voluntary isometric contraction (MVC)), and muscle onset latency. Cervical strength was tested isometrically in pounds of force (lbf). Head mean and peak accelerations were recorded as well (G), in addition to neck circumference measured at the 7th cervical (C7) spinous process level (cm).

Participants

Eight high school female soccer players (ages 14-17 years old) completed this study, recruited through those participating interscholastically with Corner Canyon High

School (Draper, UT). Participants were randomly separated into intervention (n = 4) and control groups (n = 4), using random stratification to ensure an even distribution according to size and skill level. Subjects and their parent/guardian(s) were informed of the purpose, procedures, and risks involved with participation in the study and signed consent forms prior to their involvement in the research. Subjects were excluded from participation in the intervention group if they had been unable to compete in sport at any point during the 6 months prior to pretesting due to a clinically diagnosed concussion or neck injury, were suffering from an injury to the head or neck at the time of data collection, or were unable to complete supervised plyometric intervention (due to injury, extended time away from team, etc.). The study and procedures were approved by the University of Utah Institutional Review Board.

Instrumentation

Pre and posttesting were performed at Corner Canyon High School. Testing consisted of pre and postintervention sessions for data collection. Muscle activation patterns were recorded using a 16 channel wireless EMG system (TeleMyo DTS, Noraxon, USA) with surface electrodes placed on the skin of the participant over the involved muscle bellies (found by performing corresponding manual muscle tests). Medical tape was utilized to keep sensors stationary, as necessary. Head impact acceleration values were recorded with a 24G Accelerometer (3D DTS, Noraxon, USA) placed on the posterior aspect of the skull, held against the head using a headband, synced with the EMG system, and worn during pre and posttesting heading procedures (Figure 1).

Figure 1. Upper trapezius electrode and accelerometer placement.

A MicroFET 2 handheld dynamometer (Hoggan Health, USA) was implemented for isometric strength measurements of the cervical muscles (Figure 2), and neck girth was assessed using a standard metric tape measure.

Maximum voluntary contraction (MVC) data was collected during the neck flexion, extension, and lateral rotation isometric strength testing. Data collected through the EMG system was sampled at 1200 Hz, amplified and band pass filtered between 10-500 Hz. The data was then analyzed and processed using MyoResearch software from Noraxon.

Pilot testing was performed prior to the implementation of the study procedures to ensure consistent instrumentation output and software reliability.

Figure 2. Noraxon™ 24 G DTS 3D accelerometer; seen under headband in Figure 1.

Procedures

Descriptive data was recorded prior to pre and posttesting procedures (Table 1). Neck girth was assessed before any activity, measured by recording the circumference of the neck (cm) at the level of the C7 spinous process.

Participants then performed a standard warmup of 30 seconds of both counterclockwise and clockwise rotations, followed by 2 sets of 30 second stretches of neck flexion, extension, and bilateral lateral rotation.

Table 1. Subject Demographics

	Group	Mean
Age	All participants (n = 8)	16.24 ± 1.07 years
Height	Control (n = 4)	161.29 ± 6.35 cm
	Plyometric Training (n = 4)	170.50 ± 6.03 cm
Mass	Control (n = 4)	55.91 ± 7.72 kg
	Plyometric Training (n = 4)	54.66 ± 8.25 kg
Grade	Control (n = 4)	10.50 ± 1.5 years
	Plyometric Training (n = 4)	9.75 ± 1.25 years

After the warmup procedure was completed, EMG marker set up was performed to assess muscle activation in the SCM and trapezius, with isometric strength quantified simultaneously. Participants were seated in an upright posture with arms at their side to limit accessory muscle recruitment. Neck flexion, extension, and bilateral lateral rotation were measured utilizing 3 second MVCs followed by a 30 second rest period, for 3 separate trials. The mean value of the 3 trials was recorded. The dynamometer was placed at a central location on the participant's forehead when assessing neck flexor strength, just superior to the occipital protuberance when assessing neck extensor strength, and on the lateral temporal bone when assessing lateral rotation. MVCs were quantified using the highest amplitude from the strength assessments for both the SCM and trapezius. Muscle activation and neck strength recording protocol was based on methods performed in previous literature.[5,14] The primary researcher performed all pre and posttesting measurements.

Following the MVC and strength assessments, participants were fitted with a 3D accelerometer, placed directly over the external occipital protuberance and held in place using a Velcro strap headband. Individuals then performed sport-specific movements using the head and neck to best simulate muscle activation patterns and head impacts during competition. A "header" repetition trial was performed at a low velocity concurrent with common drills performed during a typical soccer practice. Balls were thrown at head-level from 3 meters away by the researcher at 3 reference points (-60 degrees, 0 degrees, and 60 degrees from a straight ahead position), with the attempted goal of returning the pass to the researcher. Following the trial period, 15 additional repetitions were performed (5 from each reference point) at a pass velocity of 6 meters/second (estimated prior using a standard stopwatch), with maximal effort used in the return passes. The accelerometer and EMG sensors were worn simultaneously during the heading trials. EMG data was collected during the high intensity trials to determine peak muscle amplitude and muscle amplitude area (normalized to maximum voluntary contractions), and muscle onset latency. Acceleration data were also recorded during the high intensity trials, in an effort to quantify the ability of the cervical musculature to control excess movement of the head-neck complex during impact. Air pressure of the soccer ball was kept constant, at a standard measurement according to high school soccer rules. The same ball was used for all pre and posttesting. Heading procedures were modeled after previous research studies investigating the impact effects of acute soccer heading.[5,7,16] Identical testing protocols were performed for both pretest and posttesting sessions.

Intervention

An 8 week plyometric and functional training program was incorporated into regular training schedules for the participants in the intervention group. The program consisted of 3 drills to be performed 3 times per week: partner ball tosses for accuracy, partner ball tosses for distance, and partner ball tosses for speed. The accuracy drill involved 3 meter, low velocity tosses performed from a straight ahead position, as well as 90° right and left of the participant with the return passes attempted as accurately as possible. The distance drill included 6 meter, medium velocity headers executed with maximal effort to a straight ahead area, as well as 3 meters to the left and right of the designated target. Lastly, ball tosses for speed required the athlete to be seated in a hook-lying position (seated, feet flat on the ground and knees flexed to 90°) while completing as many return passes as possible in a 20 second time period. Over the course of the 8 week intervention, weeks 1 through 4 required 1 set of 15 repetitions, 3 times per week, while weeks 5 through 8 required 2 sets of 15 repetitions, also performed 3 times per week (Table 2).

Participants were provided demonstration of the heading activities, given forms to track dates that the heading intervention was performed, and were continuously monitored for any discomfort, pain, or potential injury during the intervention. An 8 week plyometric intervention has been shown to produce significant changes in power and performance in female soccer players,[18] as improvements were seen with exercises performed at least once per week. These findings, in addition to previous research related to neck strength interventions, provided a basis for the selection of an 8 week protocol for this study.

Table 2. Plyometric Training Intervention

Exercise	Description	Weeks 1 - 4	Weeks 5 - 8
Partner Ball Tosses for Accuracy	3m from partner; 5 low velocity passes from -90°, 0°, and 90°	1 set x 15 repetitions 3x per week	2 sets x 15 repetitions 3x per week
Partner Ball Tosses for Distance	6m distance; max effort to 3m left, right, and to partner	1 set x 15 repetitions 3x per week	2 sets x 15 repetitions 3x per week
Partner Ball Tosses for Speed	Hook-lying position; 1m headers for speed	2 sets x 20 sec 3x per week	3 sets x 20 seconds 3x per week

Data Analysis

Signal processing was performed to ensure proper data entry and analysis, particularly given the amount of variables measured and equipment used. Rectification was used on the EMG data to give absolute values for muscle activation, and amplitude normalization was performed, normalized to the peak value of the MVC. Raw accelerometer data were used in the analysis, as impact measurements were clearly discernable. For peak acceleration trends, periods were normalized by time to account for variability in the heading repeatability, resulting in an estimated acceleration pattern of all 15 trials.

A 2 x 2 repeated measures analysis of variance (ANOVA) was used to examine group differences in pre and posttesting measurements related to strength, activation, and girth of the cervical musculature, and the acceleration of the head during impact. Statistical significance was established at $p \leq 0.05$.

3. RESULTS

Neck Girth

Neck circumference was measured at the C7 spinous process level to test for possible hypertrophy related to gains in neuromuscular control. No significance was found related to neck girth for subjects over time (mean circumference 33.21 ± 1.79 cm pretest, 33.25 ± 1.75 cm posttest), or between groups ($p \geq 0.05$).

Neck Isometric Strength

Three trials were recorded for each participant in neck flexion, extension, left lateral rotation, and right lateral rotation, with the mean value calculated for each direction, and for total mean strength in all four directions. No significant differences existed between groups related to flexion, extension, or lateral rotation ($p \geq 0.05$), although nonsignificant strength increases were present across all measured neck actions within all subjects (Figure 3).

EMG Activity

After signal processing, mean amplitude (%MVC) and amplitude area (%MVC) were calculated. Significant increases were found in mean amplitude and amplitude area over time in right upper trapezius ($p < 0.001$), right sternocleidomastoid ($p = 0.02$), and left sternocleidomastoid activity ($p < 0.001$). There were no significant differences between groups in upper trapezius activation, sternocleidomastoid activation, or total

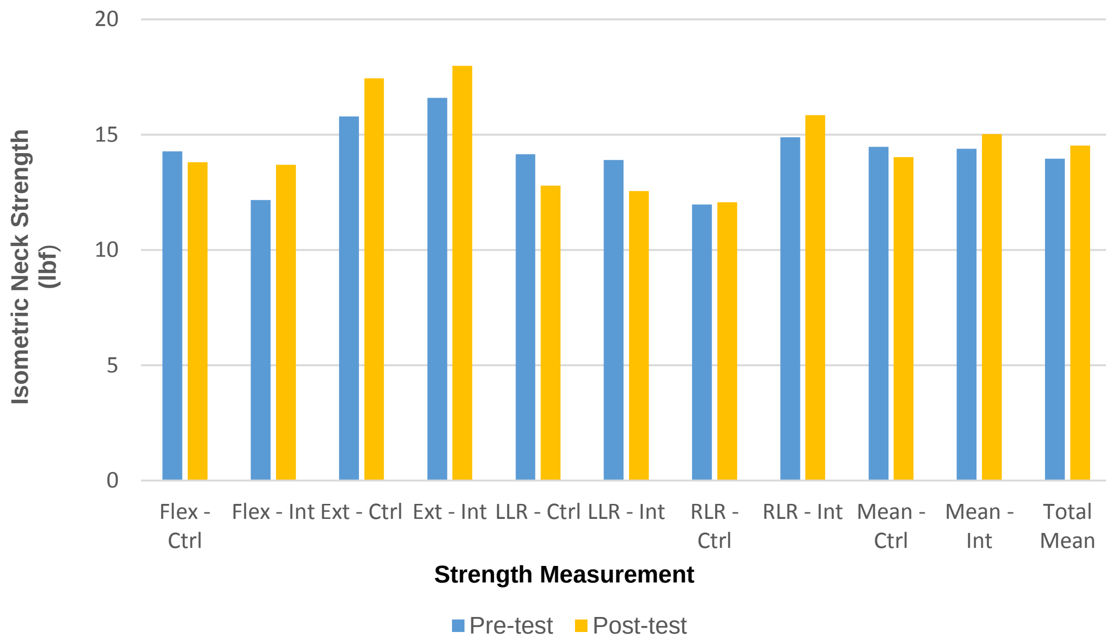

Figure 3. Changes in isometric neck strength (lbf) in flexion (flex), extension (ext), left lateral rotation (LLR), and right lateral rotation (RLR) between control (ctrl) and intervention (int) groups.

mean amplitude or amplitude area ($p \geq 0.05$), but further testing is needed given the difficulty of using EMG markers during dynamic activities such as soccer heading.

Muscle Latency

Muscle activity duration was calculated by subtracting the individual muscle onset from the muscle duration, resulting in the overall length of time (seconds) that each muscle was contracting during the heading activities. There was a significant change for both groups in right SCM offset ($p = 0.04$); however, no significant differences were found in mean duration of muscle activity during impact of the upper trapezius and sternocleidomastoid musculature ($p \geq 0.05$).

Head Acceleration

Head acceleration mean values were calculated for mean amplitude, amplitude area, mean peak impact, and maximum peak impact (G). Raw peak acceleration values were calculated for each header, with resulting mean values calculated both over time and between groups. Peak acceleration was also normalized with respect to time, to provide a generalized pattern for repetitive trials. Significant differences were found over time in z-axis amplitude area ($p = 0.04$), and normalized mean peak acceleration ($p = 0.04$). Of most interest, significant differences occurred between groups related to normalized mean peak impact ($p = 0.01$). The control group decreased in mean peak impact, from 1.157 to 1.136 G force, while the mean peak impact group increased among the intervention group from 1.197 G to 1.235 G, producing significant findings (see Table 3, Figure 4). No significant results were identified after an analysis of maximum peak G force value over time, mean peak acceleration specific to each heading trial, or maximum peak acceleration regardless of axis ($p \geq 0.05$).

Table 3. Normalized Peak Acceleration between Groups (G)

Dependent Variable	Group	Pre-Test (G)	Post-Test (G)
X – Peak	Control (n = 4)	0.701	0.472
Acceleration	Intervention (n = 4)	0.504	0.455
Y – Peak	Control (n = 4)	1.095	1.055
Acceleration	Intervention (n = 4)	1.119	1.184
Z – Peak	Control (n = 4)	1.080	1.134
Acceleration	Intervention (n = 4)	1.164	1.185
Mean Peak	Control (n = 4)	0.959*	0.887*
Acceleration	Intervention (n = 4)	0.929*	0.941*

*Multiple analysis of variance: p = .01

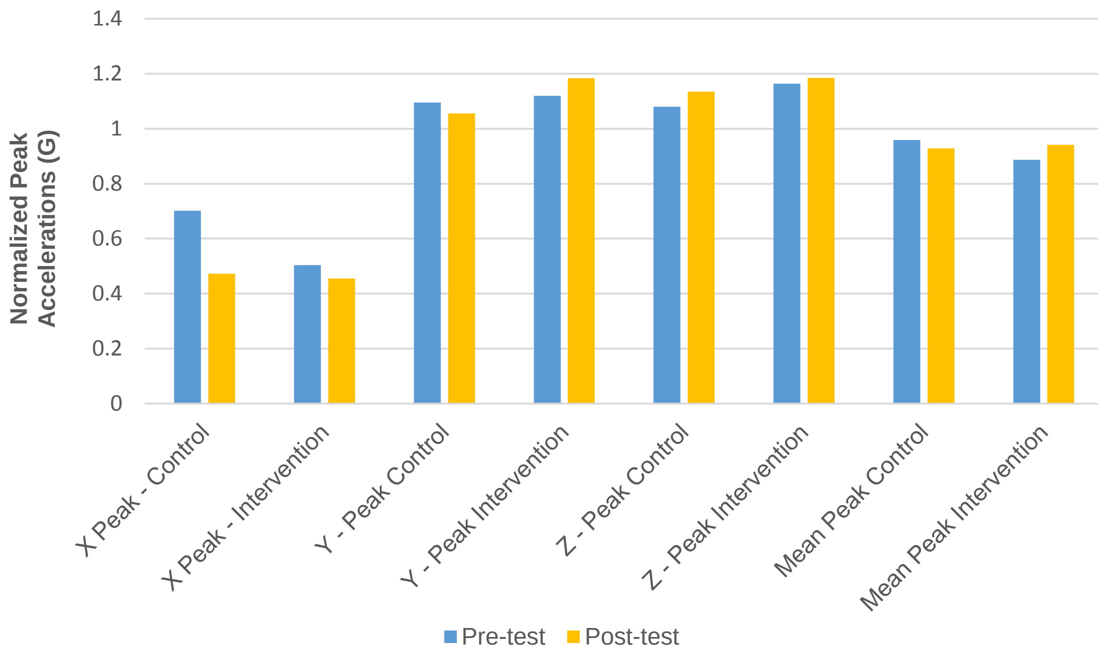

Figure 4. Normalized peak accelerations (G) by axis (X, Y, and Z), time (pre and posttest) and group (control and intervention).

Muscle Symmetry

A regression analysis revealed a significant correlation between posttesting flexion extension ratio and z-axis mean amplitude ($p=0.04$) and amplitude area ($p=0.05$), which is biomechanically supported given the orientation of the axis and the actions of neck extension and flexion. However, analysis revealed no significant relationships between neck flexion-extension ratio, right-left lateral rotation ratio, and mean and maximum peak accelerations ($p\geq0.05$).

4. DISCUSSION

The purpose of the study was to investigate whether a functional, sport-specific, plyometric intervention had any effect on the strength or activation patterns of the cervical muscles, and whether plyometric training affected subsequent head impacts among high school female athletes. The results did not confirm the initial hypothesis, but did yield clinically relevant findings.

No significance was identified related to neck strength when comparing pre and posttest isometric strength measurements. Interestingly, neck strength did increase over time in both groups, however, not at a statistically significant level. This finding may have been due to the fact that the single plane isometric manner in which strength was recorded did not exactly replicate the heading activities that was performed by the intervention group in their functional training. These results differ from those of Mansell et al,[14] who found that an isotonic strengthening program did result in significant strength changes when tested isometrically after 8 weeks. That study did not find any differences in the dynamic stabilization of the head-neck complex related to those strength gains, however, and stressed the need for an ability to dynamically test the strength of the cervical musculature. An 8 week plyometric intervention has been shown previously to produce strength gains in female soccer players,[18] with improvements identified in muscle power and performance. It is feasible, therefore, that alterations occurred in the SCM and trapezius muscles after our 8 week intervention, but did not directly translate to significant changes in isometric neck strength. Given the trend for an increase in cervical strength, however, expansion of the intervention protocol to more subjects may produce more significant findings in that regard.

It has been reported by previous research that neck strength imbalance between neck flexors and neck extensors is positively correlated with head angular acceleration measurements, and is, therefore, a possible predisposition to increased severity of head impacts during soccer.[7] A regression analysis was performed for the purposes of our study to look at ratios between neck flexor and extensor strength, and left and right lateral rotation. A significant positive correlation existed between flexor/extensor ratio and z-axis amplitude. As opposed to a potential predisposition for higher impact forces, the relationship signifies an increased ability to generate forces along the sagittal plane given increased strength and power in the cervical neck flexors, a common action in soccer activity.

Contrary to the hypothesis, significant differences were found in normalized mean peak head impacts after calculating the mean of the triaxial acceleration measurements. The time normalization was done similarly to previous research investigating gait analysis,[19] in an effort to produce a generalized estimation of the average forces experienced during a heading motion. The normalizations calculate mean values for evenly distributed periods within the heading protocol, as opposed to the high amplitude variability produced within the raw acceleration data. Peak accelerations were higher in the intervention group compared to the control ($p \leq 0.01$), with those who performed the heading intervention increasing their normalized mean peak impact by 0.038 G, while the mean peak acceleration of control subjects decreased by 0.021 G. The normalization of the data may better replicate the forces placed upon an individual by direct contact with the soccer ball, as opposed to the purposeful generation of acceleration on the return header during the testing trials that generate forces up to 10 G. The normalization peak data caused by the bracing of the head-neck complex by the cervical muscles may be more applicable to actual soccer participation, given that the neck is more often used to stabilize the skull as opposed to returning low velocity passes as seen during the testing protocol. However, raw peak values were useful in comparing the testing trials to soccer participation, in which forces of 15-30 G are commonplace. Mean peak acceleration values were calculated for each header during the testing protocol, providing an overall estimate of maximum forces generated during heading activity (Figure 5).

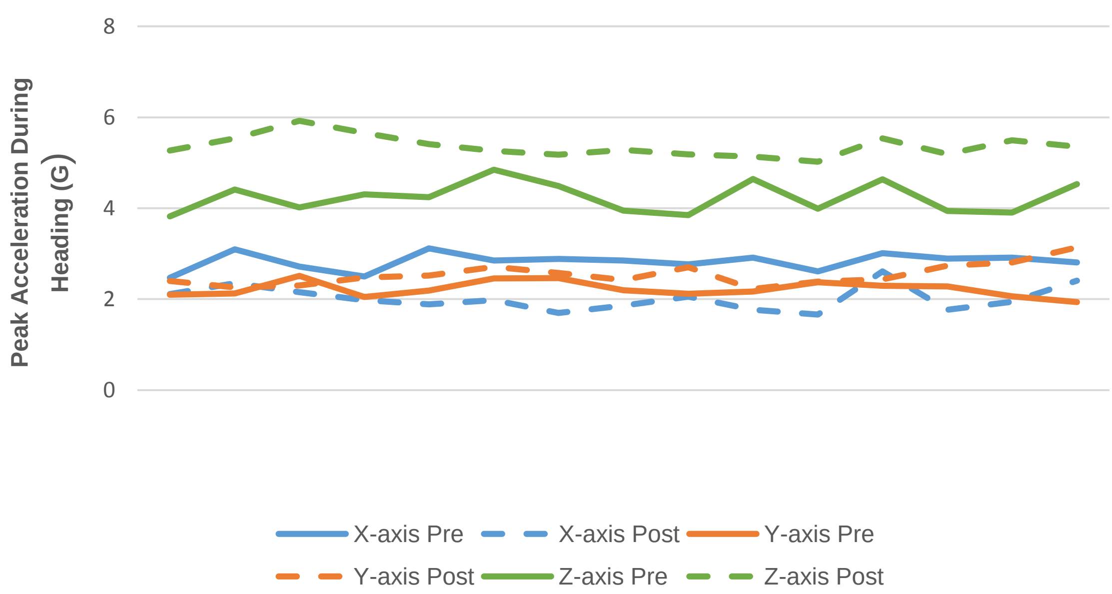

Figure 5. Raw peak acceleration across heading trials by axis (X, Y, and Z) and time (pre and posttest).

The increase in normalized peak acceleration in the intervention group may be due to increased neuromuscular control from the repetitive heading training, given that an emphasis of the sport-specific intervention was to improve the ability to control the ball for both accuracy and power. These results are similar to previous research that found that neck strength, when tested isometrically, was either not correlated with increased head impacts,[6] or was actually directly related to higher mean impacts throughout participation for those with strong necks. [20] Further research needs to be performed as it relates to functional training and the resulting distance and accuracy of soccer headers, and whether quantified neuromuscular control of the neck musculature may play a role in the determination of impact severity as it relates to purposeful use of the head-neck complex during participation.

Our findings indicate that increased sport-specific training results in higher peak forces during medium velocity, repetitive heading activity. This may be due to the fact that those in the intervention groups may have more neuromuscular control, and, therefore, are able to produce more force during a simulated soccer header. Research reported increased head acceleration as a valid predictor of concussion predisposition,[13] but little research exists related to the role of neuromuscular control in limiting subsequent forces placed within the skull that may cause a coup or contrecoup injury to the brain. The ability of the neck musculature to actively brace the head-neck complex for impact has been theorized to limit concussive forces placed on the skull,[5] and this study indicates that a functional training program may have an effect on the cervical muscles ability to generate force during soccer participation. More research needs to be performed to determine the ability of a plyometric intervention in limiting impacts during soccer practice and game activities, which would give further credence for its use in a practical application.

The study had several limitations, including a small sample size resulting predominantly from the intervention being completed during offseason team training. Interest among the girls' soccer team was difficult to sustain from in-season to offseason, with attrition occurring as a result. Incorporation into in-season practices would be a beneficial way to apply the study to a larger number of participants. Additionally, this would increase compliance to the intervention program, as adherence could be easily monitored by researchers and coaches within the team practice setting. For the purposes of this research, participants were given explicit verbal and written instructions on the intervention exercises, and were instructed to track dates that the exercises were performed on an exercise log prepared by the primary researcher. However, given that much of the heading training occurred outside of direct coach supervision, it is an additional limitation of this current study.

Further research should investigate an expanded model of this study, including more participants, in-season integration, and the potential use of accelerometers during actual soccer practice and game competition. For the purpose of this research, a replicable, repeated heading protocol was useful in tracking changes over time and between groups, but the tracking of real-time head impacts would be very beneficial in the practical application of a sport-specific training protocol. Additionally, expansion of a plyometric intervention while simultaneously investigating gender differences may lend insight into the gender discrepancies that exist in concussion epidemiology as it relates to biomechanical and physiological differences between male and female soccer players.

5. CONCLUSION

This study investigated the effects of a plyometric, soccer specific intervention on cervical muscle strength, activation patterns, and subsequent impacts during heading activities. It was hypothesized that those in the intervention group would exhibit an increase in strength and subsequent decrease in head accelerations after the eight week intervention. Increases in peak accelerations were seen over time in the intervention group compared to the control. This resulting increase in impact severity could be the product of improved neuromuscular control after repeated heading training, but more research needs to be performed to determine the susceptibility of brain injury in those demonstrating an improved ability to deflect the ball during soccer participation. As concussions in soccer increase among participants, neck strength may be an influential factor in the determination, or prevention, of debilitating brain injury. Long term cognitive deficits, subconcussive trauma, and underlying pathologies directly related to repetitive impacts to the skull may be preventable with the proper understanding of the impact forces sustained during sport-specific movements. Identifying potential predispositions is key in the prevention of brain injury among athletes, and further investigation into the role of dynamic control and stability of the neck musculature may lend insight into the biomechanics of the head-neck complex during sport participation.

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