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Cervical Muscle Strength and Kinematics during an Unanticipated Perturbation in University Aged Male and Female Rugby Athletes

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Abstract

Introduction: Female athletes participating in contact sports demonstrate a concussion injury risk factor that is two times greater than their age-matched male counterparts. Recent literature has outlined the importance of neck muscle strength and neuromuscular characteristics in the mitigation of excessive head kinematics. Rugby is a contact sport in which tackles comprise the mechanism for concussion, which is caused by inertial impacts. Females exhibit higher measurements of acceleration and investigating potential gender differences in dynamic stabilization of the head is warranted in rugby. Methods: Twenty-three (15 female, 8 male) university-aged rugby athletes participated in kinematic analysis; and a series of clinical tests of the cervical musculature. Neck strength was measured using handheld dynamometry. Electromyography and accelerometers were used to analyze activity of the sternocleidomastoid, upper trapezius, external and internal oblique muscles; as well as to quantify head, neck, and trunk change in velocity during a simulated unexpected dynamic task. One-way MANOVAs were used to determine gender differences in anthropometrics, muscle activation, and head kinematics. Independent t-tests were used to compare neck muscle endurance. Results: Males demonstrated greater neck girth (p=0.000) 95% CI females [33.45, 35.91] males [40.03, 43.40], head girth (p= 0.008) 95% CI females [55.08, 57.04] males [57.38, 60.09], and head-neck segment mass (p=0.002) 95% CI females [5.88, 6.83] males [7.09, 8.39]. Isometric strength was significantly different with males demonstrating 40-60% greater strength. Males demonstrated 43% greater muscle endurance than females. Males had a statistically significant greater change in velocity of the head in the sagittal plane. Discussion: In agreement with current literature, males and females demonstrate differences in their ability to stabilize the head in dynamic situations. This data suggests even female competitive rugby players demonstrate significant clinical factors that increase the risk of concussion. Determining injury risk predictors between male and female rugby athletes can help to design specific injury prevention interventions.

Keywords rugby; neck muscles; neck kinematics; athletic injury, sport related concussion

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Introduction

Concussions in sport are a concerning healthcare issue with an increased prevalence in contact sports like football, ice hockey, and rugby. With an estimated 1.6-3.8 million sport-related concussion incidences occurring annually within the United States, this form of brain injury has become a pervasive part of both sport and healthcare [9]. A concussion is defined as a traumatic brain injury induced by biomechanical forces [16]. These forces can be caused by both direct impact to the head, or indirect forces elsewhere on the body transmitting an impulse force, causing rapid accelerations and decelerations of the brain. This then leads to a disruption in neurological functioning [16].

The musculature of the neck has been recently studied as a mitigating factor for excessive head kinematics during perturbations as it plays a vital role in stabilization and control of the head during dynamic situations [6,11,12]. Strength, anthropometrics, and neuromuscular control of the cervical musculature are factors consistently referenced within the literature. Current research suggests that those with greater strength of the neck musculature display decreased measures of head acceleration [6,11,12]. Those with decreased cervical musculature strength are said to have a lesser ability to absorb the impact of a force to or towards the head, therefore displaying greater neck deformation and greater kinematics of the head [12]. Often, smaller maximal strength measurements are observed in the female population; with a 20-50% differences between sexes [5,11,22]. Greater cervical muscle strength is seen in conjunction with greater neck girth. Those with a smaller measurable neck circumference tend to be of the youth or female population, and typically demonstrate increased acceleration of the head-neck segment [5,11]. Additionally, angular acceleration of the head is reduced when strength measurements between the neck flexors and extensors are relatively symmetrical, as co-contraction creates a stronger neck segment [10].

Differences in head kinematics have also been observed in the event of known and unknown force application [11,15,22]. When an individual is anticipating a potential force exerted on the body, anticipatory muscle activation, or “bracing for impact”, creates rigid segments in the body and minimizes acceleration. This is true for the head-neck segment. An external force applied to the body causing movement from its original placement is referred to as a perturbation. When a perturbation is anticipated, athletes display both faster and greater measures of cervical muscle activation than in unanticipated scenarios [1,11]. Males and females have been shown to utilize the neck musculature differently to minimize head acceleration in known and unknown perturbations [2]. Males tend to rely on the use of maximal strength; while females draw on neuromuscular activation techniques to achieve similar head kinematics. However, greater measurements of head acceleration and change in velocity are consistently demonstrated in the female population [11,22].

The female athlete population is of particular interest due to their increased susceptibility to concussions in comparison to both skill and age-matched males in various sports [8,14,18]. With rugby being a high-contact sport, consisting of various known and unknown forms of high-speed contact, such as tackles, female rugby athlete injury risk is of particular interest. Sport-related concussion prevalence in female rugby players competing at the NCAA level have been reported at 6.2% of all reported incidents [19]. The current study investigated the differences in neck muscle strength, endurance, and anthropometrics in male and female rugby athletes. Additionally, muscle activation characteristics and kinematics of the head and neck in the event of a sport-specific simulated unanticipated perturbation in rugby athletes were observed. It was hypothesized that participants, specifically females, who exhibited decreased strength and size of the neck musculature would demonstrate a greater kinematic response to an unexpected blow. This is due in part to the previous literature indicating that females consistently display decreased neck strength and increased head kinematic measurements than male counterparts, and subsequently greater risk of concussion.

Methods

Participants were current athletes from a university varsity team or club rugby league within the area. Participants were provided with informed consent, as well as the 2019 PAR-Q+, Neck Disability Index, and the Sport Concussion Assessment Tool (SCAT5). These questionnaires and testing protocols determined fitness to participate in physical activity, as well as any risk potential that may exist when completing the current study. Participation in this study was completely voluntary and was approved by the University Research Ethics Board (REB 18-48).

Anthropometric measurements including height, weight, head girth, neck girth, and head-neck segment length were measured and recorded for each individual. Head and neck girth were both recorded in centimeters using a flexible measuring tape. Head girth was measured at standard bony landmarks of the skull including the nasion, inion, above the helix of each ear. Neck girth was measured just above the thyroid cartilage. Head-neck segment length was also measured using the flexible measuring tape and was taken from the vertex of the head to the spinous process of the seventh cervical vertebrae. To determine head-neck segment mass, participants' total body weight was multiplied by a pre-determined, gender-specific ratio of head-neck segment to total body mass percentage. This percentage was 8.26% for males and 8.20% for females. This method has been used in numerous studies that have also analyzed acceleration of the head-neck segment [15,22].

To test the isolated strength, endurance, and activation abilities of the cervical musculature, two clinical tests were performed. This included Handheld dynamometry and the Isometric Endurance Test (IET) of the cervical musculature. Handheld Dynamometry was used to measure peak isometric muscle force of the cervical musculature using the wireless MicroFet 2 Handheld Dynamometer (MicroFet2, Hoggan Scientific, UT, USA). Strength measures were recorded in kilograms of force (kgf). Strength measures were self-resisted based on a procedure that has been shown to have good to high reliability [23]. Participants performed flexion, extension, left and right lateral flexion, left and right lateral flexion with rotation, and left and right pure rotation.

This IET test was performed in accordance with the methods used in a recent study that looked to establish reference values for said test [24]. Participants were in a supine crook lying position and instruction was given to tuck their chin, followed by a slight lift of their head 2-3 cm off the table and were instructed to hold the position as long as possible.

In order to collect kinematic data that was rugby-specific, a laboratory simulation of an unanticipated post-tackle landing maneuver was created. This protocol mimicked the head-neck segment to avoid head contact with the landing portion of a tackle in which athletes must dynamically control the movement of the surface.

Surface electromyography was used to measure electrical activity of the sternocleidomastoid (SCM), upper trapezius (UT), external obliques (EO), and transverse abdominus/internal oblique (TrAIO) during the simulation. This was measured using the Delsys Trigno Wireless EMG system. Sensors were placed directly over the muscle belly of each individual muscle, running parallel to the muscle fibres, and were placed according to SENIAM guidelines. Prior to placement of each electrode, the skin was shaved and cleaned with an alcohol wipe.

From the Delsys Trigno Wireless EMG System, three wireless triaxial accelerometers were used to quantify the acceleration and deceleration of the head, neck, and trunk as a measurement of g. The three sensors were placed on the vertex of the head, the C7 spinous process, and L5 spinous process. A swim cap was used for the head in order to keep the accelerometer fixed to its vertex.

To normalize running speed within the simulation, maximal sprint speeds were collected using the Fusion Sport Smart Speed timing gates (Fusion Sports Inc., Coopers Plains, AUS). Timing for each sprint was averaged and converted to one's maximal speed by dividing the 2-metre distance by the average time. This data was then used to create a speed range for the unanticipated post-tackle landing.

Participants were required to run 66.7% (two thirds) of their maximal sprint speed down the centre of the lab. Three familiarization trials were performed, and feedback was given on timing in order for the approach speed controlled to be 66.7% ± 10% of the participant's average maximum run speed. After passing the first gate, one of the two gates on either side of the mats would light up, indicating an "unexpected" direction in which the participant had to dive (Figure 1). Participants were given a rugby ball and instructed to dive as they would normally in the situation of either a tackle or the completion of a try. EMG and accelerometer data were collected and recorded for each dive.

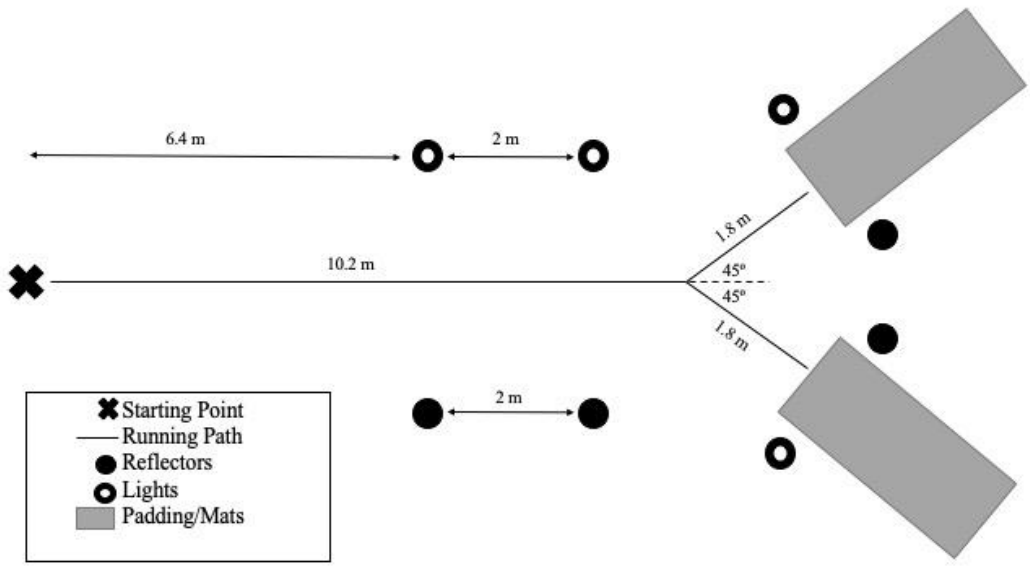


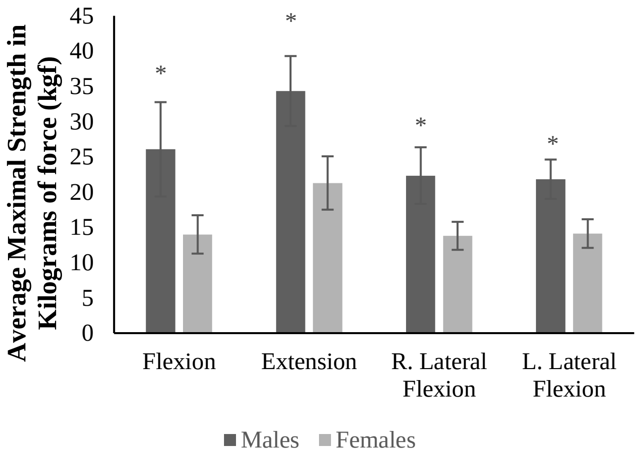
Fig. 1. Schematic representation for controlled laboratory simulation of post-tackle dive performed by participants.

EMG signals were normalized to each individual muscle through maximal voluntary isometric contractions (MVIC). Raw EMG signals were full-wave rectified and processed using a fourth-order, low-pass Butterworth with a cut-off frequency of 6Hz. All trials were magnitude normalized to MVIC trials performed. All analysis was performed in Delsys EMGworks Analysis. Acceleration data was converted to change in velocity by multiplying the average trial time by the acceleration measurement for that trial. All acceleration data collected was also processed using a low-pass fourth-order Butterworth.

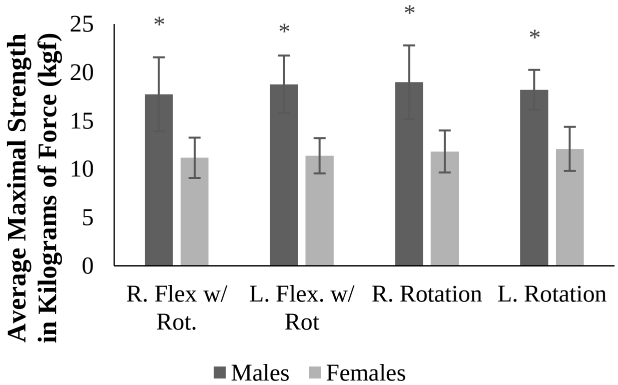
Statistical analysis was performed in SPSS 22.0 for Windows 10 (SPSS Inc., Chicago, USA). Independent t-tests were used to compare sex differences in height, weight, and neck muscle endurance. A multivariate analysis of variance (MANOVA) was performed to compare anthropometric characteristics between males and females, including: neck girth, head girth, head-neck segment mass, and head-neck segment length. A separate MANOVA was performed to determine differences in muscle strength in all ranges of neck motion between male and female participants. Multivariate tests (Pillai trace) were considered significant at $p < 0.05$. Univariate ANOVAs were used for post-hoc testing when significant between group differences were found in the MANOVA. One-way MANOVAs were used to analyze sex differences change in velocity in the sagittal, frontal, and transverse planes. Univariate interactions were also analyzed when significant effects found. Another one-way MANOVA was performed to compare neuromuscular activation characteristics during a dynamic task between male and female participants; this included activation of the SCM, UT, EO, and TrAIO muscles.

Results

Fifteen female rugby athletes (mean (SD) age: 21.1 (±2.5) years) and 8 male rugby athletes (mean (SD) age: 25.6 (±2.9) years) participated in the study. Males exhibited greater height (179.8 ± 8.9 cm) than females (167.8 ± 5.9 cm), $t(21) = -3.861$, $p = 0.001$. In addition to this, male participants displayed greater mass (93.7 ± 11.2 kg) when compared to female participants (77.46 ± 10.5 kg), $t(21) = -3.449$, $p = 0.002$. The multivariate analysis revealed an overall significant sex effect on anthropometric measurements of the head and neck using Pillai's Trace, $F(4, 17) = 11.125$, $p < 0.000$. Univariate tests revealed significant differences in sex by neck girth $F(1,20) = 41.59$; p=0.000) 95% CI females [33.45, 35.91] males [40.03, 43.40], head girth $F(1,20) = 8.830$; p= 0.008) 95% CI females [55.08, 57.04] males [57.38, 60.09], and head-neck mass $F(1,20) = 12.098$; p=0.002) 95% CI females [5.88, 6.83] males [7.09, 8.39] . A multivariate analysis revealed an overall significant sex effect on neck muscle strength, Pillai's Trace $F(11, 11) = 4.965$; p=0.007. Univariate tests revealed significant differences in sex by all strength directions, with the exception of left UT; flexion $F(1,21)=38.248$, p = 0.001 95% CI females [11.61, 16.39] males [22.79, 29.35] ; extension $F(1,21)=50.083$, p=0.001 95% CI females [19.03, 23.55] males [31.24, 37.43]; right lateral flexion $F(1,21)=47.593$, p = 0.001 95% CI females [12.28, 15.32] males [20.26, 24.42]; left lateral flexion $F(1,21) = 57.958$, p=0.001 95% CI females [12.88, 15.36] males [20.13, 23.53]; right flexion with rotation $F(1,21)=28.968$, p = 0.001 95% CI females [9.66, 12,66] males [15.68, 19.78]; left flexion with rotation $F(1,21)=55.077$, p = 0.001 95% CI females [10.16, 12.59] males [17.09, 20.43]; right rotation $F(1,21)= 33.349$, p = 0.001 95% CI females [10.30, 13.34] males [16.89, 21.05]; left rotation $F(1,21)=40.007$, p=0.000 95% CI females [10.90, 13.27] males [16.58, 19.82]; right UT strength $F(1,21)=5.106$, p=0.035 95% CI females [26.49, 32.83] males [31.16, 39.84]. (Figure 2).



(a)



(b)

Fig. 2. Sex differences in maximal isometric strength in kilograms of force (kgf) in (a) sagittal, frontal, and (b) transverse planes of movement. * ($p<0.05$)

The multivariate analysis revealed an overall main effect of sex on change in velocity of the Vertex of the head, Pillai's Trace $F(3,18)=3.248$; $p = 0.046$. Univariate tests revealed a significant sex effect by change in velocity in the sagittal plane, $F(1,20)=7.399$; $p=0.013$ CI females [0.262, 0.472] males [0.456, 0.734]. Male participants demonstrated greater change in velocity in all planes of motion of the vertex of the head; in the sagittal, frontal, and transverse planes (Figure 3).

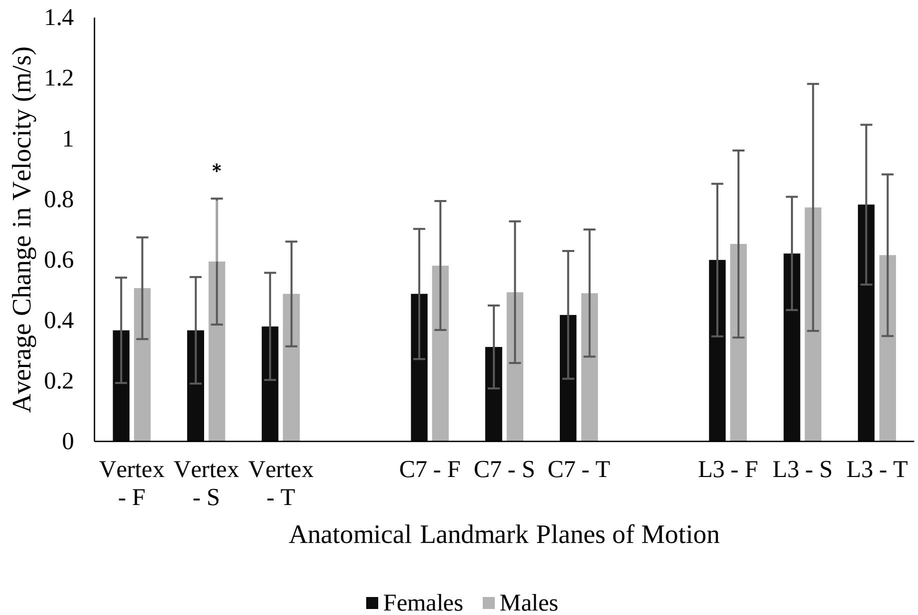


Fig. 3. Comparison of male and female participant change in velocity, in metres per second (m/s), at the Vertex, C7 and L3 landmarks in sagittal (S), frontal (F), and transverse (T) planes

Discussion

Sex differences in head-neck segment anthropometrics have been well documented. The results of the current study found that female rugby athletes, at the university level, also display significantly smaller head-neck segment anthropometrics in comparison to males similar to what has been documented in the literature[21,22]. These findings were to be expected, as previously mentioned the literature has consistently produced the same nature of results within varying athletic populations. One such study by R.T. Tierney et al.[22], found that physically active males displayed 30% greater neck girth than active females; as well as 43% greater head-neck segment mass. The smaller range of difference between the sexes in our study's population could be the result of specific training protocols performed by rugby athletes and the strength and stability required for this sport.

Female participants from the current study also displayed a much larger head to neck circumference ratio, with a 47% difference between head girth and neck girth. While conversely, males only differed in head and neck circumference by 32%. This finding is interesting as females exhibit a greater difference in proportionality between the head and neck, with the neck being roughly half the size of the head. A smaller ratio between head and neck circumference has been identified as a possible contributor to concussion risk [7]. Our results, coupled with the significant differences in head-neck segment mass, could contribute to the head acceleration experienced by female rugby athletes.

The measured circumference of the neck was positively correlated with one's cervical muscle strength. This finding was also to be expected, as greater neck girth indicates larger muscle size, which produces greater force. To our knowledge, there have been no other studies that have examined and compared neck strength in both male and female rugby players. Consistent with previous sport-related literature, female participants from the current study demonstrated significantly less strength of the cervical musculature; with a 40-60% decrease in strength measurements in all ranges of motion of the neck. R.T. Tierney et al.[21], found similar results among college-level soccer players where females demonstrated 50-53% less strength in flexion and extension when compared to their male counterparts.. In a study performed by Alsalaheen et al.[2], females demonstrated 50% less strength of the flexors than males with an output of 85.4 Newtons and 176.3 Newtons respectively. The findings of this study add to the notion that males and females display different biological characteristics contributing to their performance and risk of injury.

We observed a 43% difference in endurance between males and females, with females falling to the lower end of the spectrum. This finding is important as greater endurance of the cervical muscles has been proposed as a potential risk reducing factor for sport-related concussions [20]. The results of the current study fit with the previous literature where males exhibit greater cervical flexor endurance [3,13]. For young adults, similar in age to that of our study's population, normal endurance times have been reported as 37.91±9.17 seconds and 35.12 ± 9.09 seconds in males and females respectively [13]. The decreased values compared to those obtained in the current study could be due to the differences in the populations studied. Rugby athletes in comparison to the general population may display greater endurance as a result of sport-specific training.

Neck strength has been consistently linked to higher measurements of neck strength with decreased head and neck kinematics; specifically, linear and angular acceleration [2,4,12]. A large sum of the literature that analyzes the response of the head and neck to impact in sport, has found that female athletes often demonstrate greater kinematic measurements than males [11,15]. However, this is not always the case. There have also been studies indicating that greater strength in the cervical region does not impact kinematic response [2,17]; and therefore this biomechanical response is due to some other underlying factors. To our knowledge, this is the first study to measure kinematics during a rugby specific unanticipated perturbation and comparing between sexes. In the current study, male rugby athletes displayed significantly greater isometric strength, while also exhibiting greater linear change in velocity of the head, neck, and trunk. These results suggest that when male and female rugby athletes perform a similar dynamic task, they adopt different mechanisms of head stabilization. Perhaps these differences exist because our simulation protocol was a full body dynamic movement rather than an isolated head perturbation. We analyzed the change in velocity during the entire task rather than isolating specific time points, such as pre-impact or post-impact. As the peak change in velocity was what was analyzed and interpreted, potentially this spike in head kinematics is occurring at different phases of the sport-specific maneuver between the sexes.

Conclusion

The results of this study demonstrate that competitive female rugby athletes exhibit similar clinical risk factors for concussion susceptibility, in relation to other female athlete populations. As described in the literature, major increased risk factors include decreased cervical girth, strength, and endurance; as well as strength imbalances [20]. These risk factors were evident in the current sample, with female rugby athletes exhibiting decreased size, strength, and endurance of the cervical musculature in comparison to skill and aged-matched males; potentially hindering their ability to effectively stabilize the head. The findings of the current study are especially important as female rugby athletes play a sport in which injury risk is extremely high, including that of concussion. With the present sample exhibiting 40-60% less strength and 43% less endurance than males within the cervical musculature controlling head movement, the risk of sport-related concussion is elevated for female rugby athletes. The significant findings from this study should be further addressed in concussion prevention protocols, specifically targeting sex differences in techniques used to stabilize the head such as strength, endurance, and anticipatory activation for mechanisms of impact. In rugby athletes, strengthening protocols for all ranges of motion of the neck should be incorporated into workout regimens, especially for females.

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