DIFFERENCES IN FUNCTIONAL RECOVERY FOLLOWING CONCUSSION BETWEEN MALES AND FEMALES

by

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Concussion, a brain trauma resulted from linear or rotational acceleration to the head, represents a majority of the traumatic brain injuries (TBI) sustained each year. To understand if there are recovery differences between males and females post-concussion, this research examined males and females with matched controls for two months following the injury. In this study, a 3-dimensional motion analysis system was used to observe the trajectory of 29 anatomical locations in order to determine the peak anterior velocity of each subject's center of mass (COM, the point where the mass is equally distributed) and the medial-lateral COM sway. Symptom severity was assessed based on a 22-symptom inventory and a scale similar to the Likert scale for each symptom (ranking each symptom from 0-6). A three-way analysis of variance, or ANOVA, was performed to analyze the data in order to determine the effect of concussion, sex (male and female), time (72 hour, one week, two week, one month, and two month post-injury), and the interactions between these independent variables. It was revealed that males and females do not objectively differ in terms of the peak anterior COM velocity or COM medial-lateral displacement across the 2-month study, but that females reported more severe symptoms than males. The findings suggest that subjects of both sexes follow the same general gait balance recovery trends and that both sexes report heightened symptoms for at least two months after experiencing a concussion. Across all time points, females reported more symptoms than males, so either males are underreporting their symptoms or females are experiencing more symptoms than males.

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Introduction

Traumatic brain injury (TBI) has been identified as an injury which affects approximately 3.3 million people living in the United States (Ma, Chan, & Carruthers, 2014). Concussion, a subset of TBI, has been described as a brain injury which results from a trauma that acts upon the head and results in neurological deficits (Broglio et al., 2014; Cancelliere et al., 2014; Harmon et al., 2013; Paul McCrory et al., 2013). Correspondingly, concussion represents a majority of the TBIs sustained annually (Ma et al., 2014) and incidence rates have steadily increased over the past decade (Lincoln et al., 2011; Rosenthal, Foraker, Collins, & Comstock, 2014). Post-concussion complications such as balance control, neurocognitive function, and various signs and symptoms (Valovich-McLeod, Bay, Lam, & Chhabra, 2012) affect those who sustain a concussion, but are highly variable based on factors such as impact severity or location, loss of consciousness, history of injury, or genetics (Tsushima, Lum, & Geling, 2009). One factor in particular that has been identified to negatively affect injury-related outcomes is the sex of the individual (Marar, Mcllvain, Fields, & Comstock, 2012).

Previous research on head and neck size has identified differences between males and females. Factors such as greater head and neck mass and isometric strength have been identified in males compared with females (Tierney et al., 2005). Such differences may contribute to a greater vulnerability to the risk of concussion and affect recovery patterns for females (Tierney et al., 2005). Physiological differences between the two sexes may exist, (Covassin, Schatz, & Swanik, 2007) but in a study investigating baseline values of the Sport Concussion Assessment Tool 2 (SCAT2), no significant differences between males and females were observed (Valovich-McLeod et al., 2012). Moreover, one study found no differences between male and female neurocognitive and symptom recovery post-concussion (Tsushima et al., 2009). However other research observed that females displayed greater neuropsychological deficits than males in the first 10 days after concussion, but males reported more symptoms than females during this time period (Dougan, Horswill, & Geffen, 2014). Female athletes also may report more symptoms than males and perform worse on visual memory tests than male athletes after a concussion (Covassin, Elbin, Harris, Parker, & Kontos, 2012). Further research detailed that many of the symptoms that males and females report post-concussion are similar to those that people with post-concussion syndrome experience (Chan, 2001) and that females are linked to higher occurrences of post-concussion syndrome (Bazarian et al., 1999). One study reported that females with concussion performed worse on measures of memory, concentration, headache, dizziness, fatigue, and ill-tempered reactions to light and noise when compared to males with concussion (Farace & Alves, 2000). These studies suggest highly variable outcomes when comparing concussion recovery between the sexes.

Various studies have identified persistent gait balance control and cognitive function deficits from the time of injury and throughout a time period of up to two months post-injury, but these studies have grouped men and women together (Covassin et al., 2012; Howell, Osternig, & Chou, 2013; Ryan, Atkinson, & Dunham, 2004). While previous research has identified differences in recovery of gait balance control after concussion between age groups (Howell, Osternig, & Chou, 2015), it is still unknown if differences in recovery patterns between males and females exist. To our knowledge, there has been no research examining how gait balance control and symptom severity following concussion recover differently between males and females. As more women participate in sports (Broshek et al., 2005), it is essential to determine the role sex plays in concussion recovery so that the individual factors that influence recovery following concussion may be better understood, in order to better develop individualized treatment protocols (Paul McCrory et al., 2013).

Athletes are often allowed to return to play after sports-related concussion once with diminished symptoms and normalized gross motor control (Powers, Kalmar, & Cinelli, 2014). Typically, the clinical assessment of concussion includes a neurologic exam that assesses self-reported symptoms, cognitive function, and motor function (Harmon et al., 2013; Paul McCrory et al., 2013). However, reliance on subjective symptoms alone may lead to premature clearance to participate in pre-injury levels of physical or cognitive activities, which can ultimately affect recovery (Powers et al., 2014). One study reported that individuals with concussion could continue to demonstrate a decreased ability to control static or dynamic balance at the time they were permitted to return to play or pre-injury level activity (Powers et al., 2014). As concussion has been identified to adversely affect various locomotor functions, it is important to investigate the way in which males and females recover these abilities, independent of pre-existing gait differences (Kerrigan, Todd, & Croce, 1998), to objectively identify if concussion affects these abilities differently (Lee, Sullivan, & Schneiders, 2013).

Numerous recent studies have investigated the potential negative effects of concussion on gait using dual-task walking paradigms. In a long-term, retrospective study, individuals with concussion demonstrated slower walking speeds, more cautious gait patterns, and decreased postural stability during dual-task walking and avoiding obstacles (Martini et al., 2011). Fait et al. (2012) observed that subjects with concussion, while dual-task walking, took longer to complete strides when crossing obstacles, displayed larger minimal clearance distances from the obstacles, and performed more errors than the controls, despite recovery of clinical symptoms. Another study found that dual-task walking was negatively affected by concussion, as observed by an increased center-of-mass medial-lateral displacement and decreased anterior velocity compared with control subjects (Howell et al., 2013). Such reports indicate that dual-task research has the potential to provide health care professionals with a more accurate method of determining when it is safe for the concussed athlete to return to play (Fait, Swaine, Cantin, Leblond, & McFadyen, 2012; Register-Mihalik, Littleton, & Guskiewicz, 2013).

Despite the wealth of literature comparing concussion-related outcomes between men and women, no single study has compared objective measures with subjective, self-reported measures between sexes. Thus, the identification of subjective and objective recovery differences between sexes may help to form improved individualized management plans for each individual. The purpose of this study was to determine if differences were present between males and females on measures of symptom severity, single-task, or dual-task gait performance in reference to individually matched control subjects. Although previous literature has presented mixed results about whether males or females are affected to a greater degree by concussion, it appears that females have an increased risk of recovery difficulties when compared with their male counterparts.

It was hypothesized that female athletes may demonstrate a more prolonged recovery pattern than males relative to a control group on measures of symptoms and gait balance control from the time of injury and across the two months post-injury.

Methods

Participants

Seventy six subjects were identified and agreed to participate in the study. Of the 76 individuals, 38 were diagnosed with concussion by healthcare professionals, either a certified athletic trainer or a physician at local high schools or university healthcare facilities, and agreed to begin testing within 72 hours of injury. Concussion was defined as an injury due to a traumatic blow to the head, face, neck, or other body part with an impulsive force transmitted to the head, resulting in compromised neurologic function and acute clinical symptoms. Control participants were individually matched by age, sex, height, weight, and activity with each participant with concussion and completed the same protocol in similar time increments. Prior to data collection, the institutional review board reviewed and approved the protocol of the current study. All subjects and parents or guardians of those under the age of 18 provided informed consent prior to participation. Local school districts and university student health care centers also granted permission to perform testing with student participants.

Exclusion criteria for subjects with concussion and control subjects included: (1) lower extremity injury that may potentially affect gait patterns; (2) history of cognitive deficits, such as permanent memory loss or difficulty concentrating; (3) history of 3 or more previous concussions; (4) loss of consciousness lasting greater than one minute; (5) history of attention deficit hyperactivity disorder; or (6) a documented concussion within the past year. A verbal history was administered for all subjects during their first visit to the laboratory by a certified athletic trainer to verify that all criteria were met for inclusion in the study.

Testing timeline

The study utilized a prospective, repeated-measures design in which each subject first reported to the laboratory within 72 hours of sustaining a concussion. Subjects then returned at the approximate time points: 1 week, 2 weeks, 1 month, and 2 months following injury. Control participants were initially tested and then adhered to the same testing timeline as concussion participants.

Protocol

Participants walked barefoot at a self-selected speed on a walkway under 2 conditions: normal walking (single task) and walking while simultaneously completing an auditory Stroop test (dual task). The Stroop test consisted of the subject, while walking, listening to four auditory stimuli, either the word high or low, spoken in either a high pitch or low pitch. Subjects were instructed to correctly identify the pitch of the word being spoken, regardless of whether the pitch corresponded to the meaning of the word. The first stimulus was initiated by a photocell several strides from the initiation point to ensure steady-state gait. The 3 subsequent stimuli were presented 1 second after the response and presented in random order. Participants were instructed to not prioritize their attention on the walking or on the cognitive task specifically, but to continue walking while correctly determining each pitch. Each subject completed approximately 8 to 10 sequential trials were for each of the 2 conditions (single and dual task).

A 10-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA) was used to capture and reconstruct the 3-dimensional trajectories of 29 retro-reflective markers placed on anatomic landmarks of the subject (Howell et al., 2013). The marker trajectory data were collected at a sampling rate of 60Hz and low-pass filtered with a fourth-order Butterworth filter with a cutoff frequency set at 8Hz. The center of mass (COM) position for each body segment was calculated by the external markers and estimated joint centers. Whole body COM position data were then calculated as the weighted sum of all body segments with a total of 13 segments comprising the whole body movement. Gait events were detected from ground reaction forces collected at 960Hz using 3 force plates (Advanced Mechanical Technology, Inc. Watertown, MA). Stimulus presentation for the Stroop test was randomized using Super Lab Pro (Cedrus Corp., San Pedro, CA). A wireless microphone allowed participant responses to the Stroop test while walking. Data were analyzed for 1 gait cycle, defined as heel strike to heel strike of the same foot, for each trial.

Concussion symptoms for all subjects–concussed and control–were assessed based on a 22-symptom inventory measuring the severity of each symptom on scale similar to the Likert scale (ranking each symptom from 0-6), adapted from McCrory et al. (P McCrory et al., 2013)

Data analysis

Gait temporal-distance variables included; average walking speed: the mean forward velocity throughout the subject's gait cycle, step length and step width, determined by calculating the distances between right and left heel markers at each heel strike in the anterior/posterior and medial/lateral planes, respectively. During the gait cycle, the total medial/lateral COM displacement was obtained, as well as the peak anterior and medial/lateral linear COM velocities. The cross-validated spline algorithm from the COM position was used to calculate the linear COM velocity (Woltring, 1986). Previously, these variables have identified changes to gait performance following a concussion in young adult and adolescent age groups, from the time of injury and throughout the following one to two months post-injury (Howell et al., 2013). The mean value for each dependent variable for each subject was calculated and used in further analysis.

Statistical analysis

Walking dependent variables were analyzed using a three-way, mixed effects analysis of variance (ANOVA) in order to determine the effect of concussion, sex (male and female), time (72 hour, one week, two week, one month, and two month post-injury), and the interactions between these independent variables. For all omnibus tests, significance was set at $p < .05$ and follow up pairwise comparisons were examined using the Bonferroni procedure to control family wise type I error. All statistical analyses were performed with SPSS version 22.

Results

Participants

No significant differences were observed between the female concussion and control groups (table 1) for age (p = .863), height (p = .909), or mass (p = .830). Similarly, no significant differences were detected amongst the male concussion and control groups (*Table 1*) for age (p = .809), height (p = .838), or mass (p = .476). Both concussion and control groups were comprised of 14 females and 24 males. The testing timeline for all subjects is detailed in *Table 2*.

Gait Temporal-Distance Parameters

For average walking velocity, female and male subjects with concussion walked at significantly different average velocities from their matched controls across the 2-month testing period (time x group interaction, p = .001, η_p^2 = .072). There were no significant between-group (p = .059) or between-sex (p = .218) differences for average walking velocity. Step lengths were significantly different across the two months post-injury (main effect of time, p = .000, η_p^2 = .206); however, there was no effect of group (p = .059) or sex (p = .242). No between-group (p = .442) or between-sex (p = .360) differences were observed for step width throughout the 2 months post-concussion.

Medial-Lateral COM displacement

Dual-task medial-lateral displacement was significantly greater for males with concussion compared with male controls throughout the two-month testing period (main effect of group, p = .005, η_p^2 = .106, main effect of time, p = .001, η_p^2 = .234, Figure 1).

Similarly, females with concussion displayed greater medial-lateral displacement than their matched control subjects across the 2-month testing period (main effect of group, $p = .005$, $\eta_p^2 = .106$, main effect of time, $p = .001$, $\eta_p^2 = .234$, Figure 1). Total dual-task medial-lateral displacement for all female subjects was not significantly different from all male subjects ($p = .661$, Figure 1).

Peak Anterior COM Velocity

There was a significant time by group interaction for peak anterior COM velocity during dual-task walking ($p = .039$, $\eta_p^2 = .138$, main effect of time, $p = .000$, $\eta_p^2 = .588$, Figure 2). Follow up comparisons determined that females and males with concussion did not walk at significantly different peak anterior COM velocities during dual-task conditions compared to their matched controls across all time points ($p = .058$, Figure 2). Total dual-task peak anterior COM velocity for all female subjects was not significantly different from all male subjects ($p = .295$, Figure 2).

Self-reported symptom severity

Female and male subjects with concussion reported significantly different symptom severities from their matched controls across the 2-month testing period (main effect of group, $p = .000$, $\eta_p^2 = .437$, group x time interaction, $p = .000$, $\eta_p^2 = .277$, Figure 3). Across all time points, the severity of self-reported symptoms for all female subjects was significantly different from the severity that all male subjects reported (main effect of sex, $p = .042$, $\eta_p^2 = .058$, Figure 3).

Discussion

The results of this study suggest that while walking and performing a cognitive task simultaneously, females with concussion do not demonstrate greater COM motion control when compared to their male counterparts with concussion. However, females with concussion report more severe concussive symptoms across the 2-months post injury than males with concussion.

Previous literature has employed the use of COM motion analysis to assess gait balance stability (Howell et al., 2013; Parker, Osternig, Lee, van Donkelaar, & Chou, 2005; Parker, Osternig, van Donkelaar, & Chou, 2007). The data from this study support the previous finings when comparing medial-lateral COM displacement between participants with concussion and matched control participants during dual-task walking throughout the 2 months after the injury. Thus, as former studies have showed, increased medial-lateral COM sway potentially implies that subjects with concussion have a decreased ability to maintain balance control (Howell et al., 2013; Parker et al., 2007). However, in this study, medial-lateral COM displacement data for concussed females was not significantly different from medial-lateral COM displacement data for concussed males. This suggests that concussion may affect the gait stability of males and females in a similar manner.

Previous research has shown that peak anterior COM velocity during dual-task walking decreases in adolescents with concussion, compared to their matched controls, potentially due to a reduced ability to maintain forward momentum while walking and simultaneously completing a cognitive task (Howell et al., 2013). Throughout the study, both concussed and control subjects' peak anterior COM velocity increased, but, as evidenced by a time by group interaction, concussed subjects' velocity increased at a different rate **than control subjects**. The peak COM velocity for male subjects with concussion did not significantly vary from male control subjects during the 2-months post injury. Likewise, no significant differences were found when comparing the peak forward velocity between females with concussion and matched controls, as well as males with concussion and their matched controls. This indicates that reduced peak forward COM velocity resulting from concussion may not preferentially affect males or females to a greater degree.

Prior research identified that females reported heightened symptoms in the categories of concentration, headache, dizziness, fatigue, and pain resulting from light and noise stimulation than males, and females received worse scores on visual memory tests than male athletes (Covassin et al., 2012; Farace & Alves, 2000). The current data are in agreement with previous findings as females self-reported significantly different symptom severities than males throughout the study timeline. In fact, females reported a higher symptom severity than males regardless of whether or not they had a concussion. This suggests that while females do not objectively fare worse than males in gait balance measures, as hypothesized, they may be more likely to report greater symptom severities than males. Moreover, healthy females reported more symptoms than healthy males. Thus, these data is potentially indicate that females are more comfortable self-reporting symptom severity than males. Consequently, females may experience greater symptoms than males post-concussion, or males may not report as honestly as females.

Conclusions

Data from this study indicate that recovery differences did not exist on objective balance metrics between males and females. On self-reported measures, however, females appear to report greater symptom severities than males from the time of injury and throughout the two months following injury, when compared to a matched group of control participants. This supports the notion of an individualized approach to concussion management, as males and females may report the resolution of symptoms resulting from a concussion at different rates.

Figures

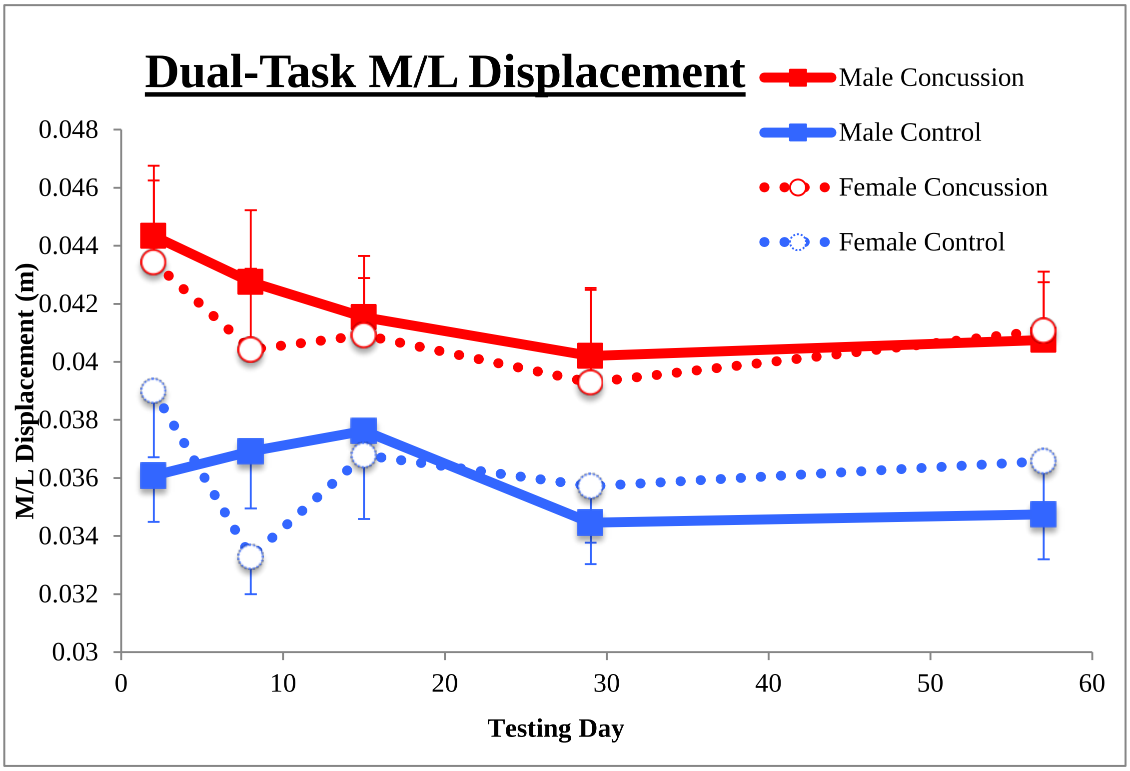

Figure 1: Average total COM medial/lateral displacement in female/male concussion and control subjects across testing time points

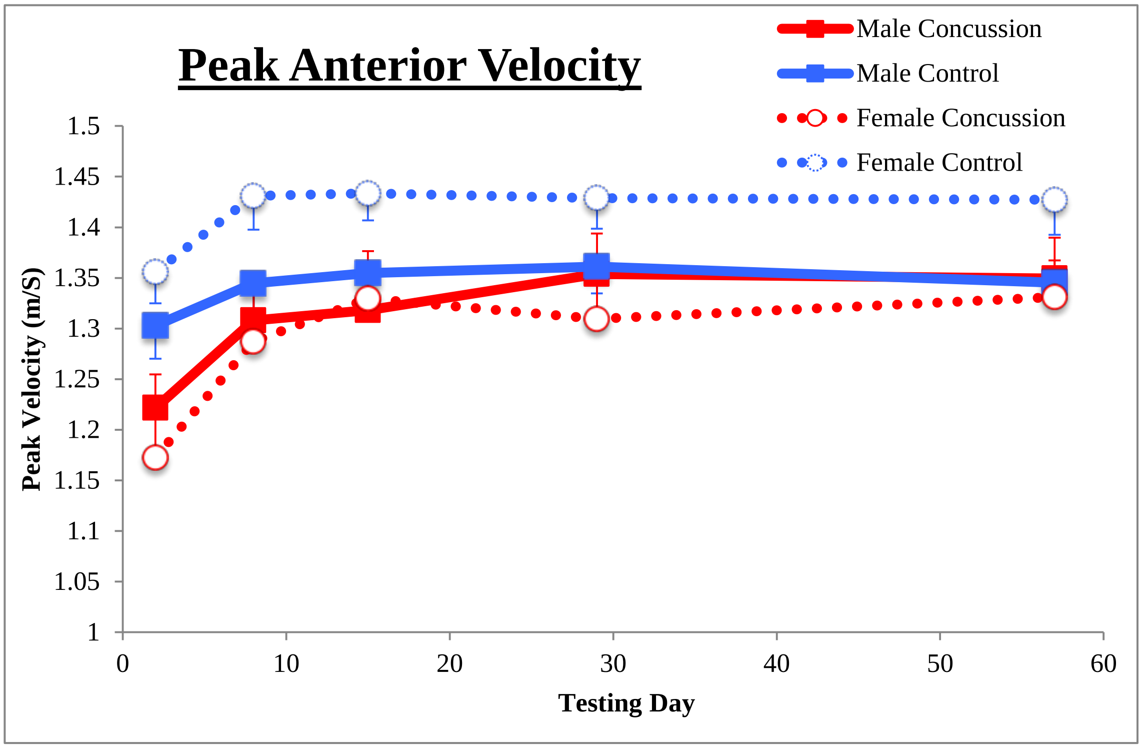

Figure 2: Average peak anterior COM velocity in female/male concussion and control subjects across testing time points

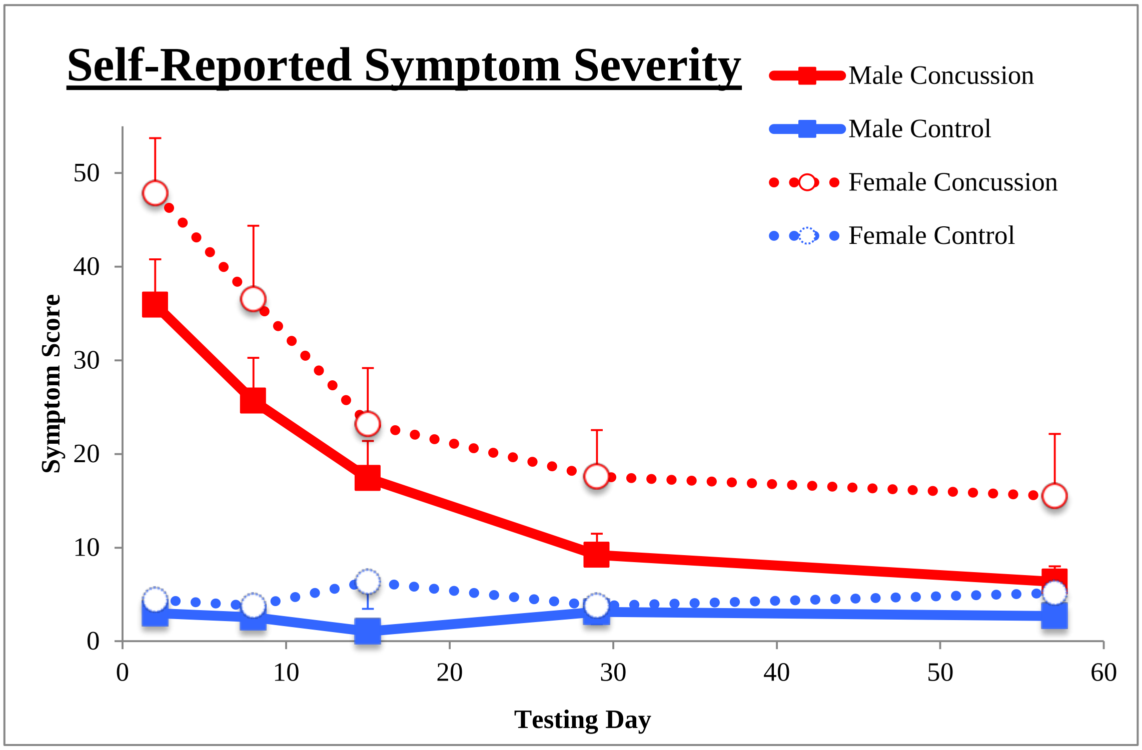

Figure 3: Self-reported symptom severity in female/male concussion and control subjects across testing time points

Tables

Table 1: Demographic Information for All Subjects

Group	*n*	Age (Years)	Age Range	Height (cm)	Mass (kg)
Female Concussion	14	18.6 (± 3.2)	14-20	165.1 (± 6.9)	65.9 (± 16.9)
Female Control	14	18.8 (± 3.3)	14-24	164.9 (± 6.2)	64.8 (± 9.4)
Male Concussion	24	17.3 (± 3.2)	14-27	176.8 (± 5.7)	76.2 (± 15.0)
Male Control	24	17.5 (± 2.8)	14-26	176.4 (± 7.5)	73.3 (± 12.8)

NOTE. Values are group mean ± SD.

Table 2: Testing Timeline for All Subjects

Group	Visit 1	Visit 2	Visit 3	Visit 4	Visit 5
Female Concussion	2.4±0.8	8.6±1.9	16.2±1.8	29.6±1.7	57.9±5.4
Female Control	__	7.3±1.8	16.0±5.3	28.1±3.5	59.1±7.8
Male Concussion	2.4±0.7	8.4±1.7	16.5±2.5	30.8±4.4	58.5±3.6
Male Control	__	7.3±1.5	15.0±1.8	30.0±2.9,	56.8±5.9

NOTE. Values are group mean days after the injury ± SD for subjects with concussion and group mean days after initial visit ± SD for control subjects

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