Sex-Based Differences in Cognitive Deficits and Symptom Reporting Among Acutely Concussed Adolescent Lacrosse and Soccer Players

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Background: Research on the acute effects of a concussion among lacrosse players is limited, and postconcussion patterns between male and female athletes have yet to be clearly established. Differences in the style of play and protective gear worn among male and female lacrosse players potentially confound a direct comparison of sex-based differences in this population.

Purpose: To explore sex-based differences in postconcussive neurocognitive functioning and symptom reporting outcomes in concussed adolescent male and female lacrosse players compared with a group of soccer players.

Study Design: Cohort study; Level of evidence, 3.

Methods: A total of 224 adolescent lacrosse players (112 male, 112 female) aged 13 to 17 years (mean [±SD] age, 15.43 ± 1.09 years) were included in this study. A comparison group of soccer players was added and matched to lacrosse players based on age and sex to address confounding sport differences in male and female versions of lacrosse. All athletes underwent baseline and postinjury testing within 3 days of an injury using the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) tool. Data were analyzed at baseline using a multivariate analysis of variance (MANOVA) with sport and sex as between-participant factors. A 2 × 2 × 2 mixed-factorial MANOVA was also conducted for sex and sport comparisons at baseline versus after a concussion. Ancillary analyses evaluated sex-based differences in exceeded reliable change indices (RCIs) using an independent-samples *t* test and established postinjury cutoff scores reflective of a protracted recovery using chi-square tests.

Results: All athletes had a significantly worse cognitive profile and greater endorsement of symptoms after an injury ($F_{5,216}$ = 30.30, $P < .001$, η_ρ^2 = .41). Sport yielded a significant main effect ($F_{5,216}$ = 2.36, P = .04, η_ρ^2 = .05), but subsequent univariate analyses were nonsignificant ($P > .05$) across all neurocognitive and symptom outcome variables. Likewise, there were no significant interaction effects for sport × time ($F_{5,216}$ = 1.46, P = .21, η_ρ^2 = .03) or sport × sex × time ($F_{5,216}$ = 2.09, P = .07, η_ρ^2 = .05), indicating that lacrosse and soccer players respond similarly on neurocognitive testing and symptom reporting after sustaining a concussion. Regarding sex-based differences, female athletes had a significantly greater neurocognitive decline and increased symptoms after a concussion relative to male athletes, regardless of the sport type (sex × time interaction effect: $F_{5,216}$ = 3.86, P = .002, η_ρ^2 = .08), with the relationship between concussions and sex demonstrating a medium- to large-sized effect. Female athletes demonstrated a significantly greater number of exceeded RCIs ($t(216.16) = -3.732$, $P < .001$), with 59% of male and 74% of female athletes with at least 1 RCI decline. Approximately 13% of male athletes, compared with 30% of female athletes, demonstrated scores indicative of protracted recovery at a 75% sensitivity (χ^2 (1, N = 224) = 9.43, P = .002).

Conclusion: Athletes performed more poorly on computerized cognitive screening tools and reported greater symptoms after an acute concussion relative to their baseline performance. Female sex may be a modifier of an acute concussion outcome, given that female athletes in this study performed significantly worse than male athletes across all neurocognitive measures and reported greater symptoms relative to their baseline testing compared with male athletes, regardless of the sport played. Female athletes were also more likely than male athletes to demonstrate scores on neurocognitive testing that exceeded reliable change cutoffs and were predictive of a protracted recovery. The practical significance of these findings should be further verified by prospective longitudinal research given the medium- to large-sized effect demonstrated for the overall relationship between sex and concussions.

Keywords: lacrosse; soccer; head injury; female athletes

High school lacrosse has the second highest incidence rate of sport-related concussions in male (0.30 per 1000 athlete-exposures) and female (0.20 per 1000 athlete-exposures)

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sports,[35] second only to football among male athletes and soccer among female athletes (0.60 and 0.35 athlete-exposures, respectively). The frequency of concussions among adolescent lacrosse players is expected to rise annually by 17% for male and 14% for female athletes,[35] which is concerning given that lacrosse is the fastest growing sport in high school athletics.[55] The National Federation of State High School Associations estimates that 190,000 high school students currently play lacrosse.[43]

Male and female athletes play very different versions of the sport of lacrosse. Male lacrosse is considered a collision sport in which body checking is permitted, while female athletes play a contact sport in which intentional body checking is penalized. The protective equipment required by male and female athletes thereby differs as well. For instance, lacrosse male players wear a full helmet with a face shield, while female players only require protective eyewear and soft headgear.[26] These different styles of play and equipment contribute to differing injury patterns among sexes, rendering male and female versions of the sport not directly comparable in the literature.[35,36]

Research on concussion injuries among lacrosse players is limited, as previous research has focused predominantly on male football players, despite a growing prevalence in other sports and among female athletes.[9,33,35,39] There is an emergent need to expand this focus, given that 42% of high school athletes are female,[44] and female athletes may demonstrate a 2-fold risk of sustaining a concussion.[4,35,37,58] Some studies have identified female sex as a potential risk factor for poorer neurocognitive test performance, more severe symptoms, and prolonged recovery times after a concussion,[5,6,10,12,13] while others have found no sex-based differences in outcomes after a concussion.[22,24] Studies directly comparing male and female athletes after a concussion often utilize soccer players as participants because the sport is played similarly between sexes, thus reducing the potential confounders related to sport differences.[12,35,59]

The evaluation of acute concussive injuries involves a multimodal approach in which athletes' symptoms and performance on objective measures are considered.[40,41] Neurocognitive testing is a widely accepted objective screening tool for the evaluation of concussions.[30] Sport teams from amateur to professional levels have adopted a serial assessment model for neurocognitive testing that entails a comparison of preinjury (ie, baseline) to postinjury results using empirically established reliable change indices (RCIs). RCIs provide an objective cutoff score that indicates that a meaningful change in test performance occurred (eg, neurocognitive decline due to a concussion). The use of neurocognitive testing during the acute phase of a concussion has also demonstrated value in predicting those athletes who will go on to experience a protracted recovery beyond the typical 7- to 10-day recovery time frame expected for concussed adolescents.[9,39]

The purpose of the current study was to explore sex-based differences in postconcussive neurocognitive functioning and symptom reporting in acutely concussed adolescent male and female lacrosse players compared with a group of soccer players. Soccer players were included in the study to address the potential confounders related to sport differences in male and female versions of lacrosse. In this study, athletes' neurocognitive performance and symptoms were examined at baseline and in the acute phase of a concussion and then subsequently compared with established clinical cutoffs to further speculate the recovery trajectory among male and female athletes.[28,31]

METHODS

Participants

Participants were obtained through a review of existing medical records using a large existing database provided by ImPACT Applications Inc. The director of programming provided the data and was blinded to the purpose of this study. Data were extracted based on active participation in lacrosse, with athletes listing the United States as their country of origin, and the presence of baseline and postinjury testing data. The initial sample consisted of 3635 athletes. A subsequent sample of soccer players (n = 2212) was added to the study to serve as a control group.

Further inclusion and exclusion criteria were applied. Included participants (1) were adolescent athletes aged 13 to 18 years, (2) listed English as their primary language, (3) reported no history of a neurological condition (eg, seizure disorder, brain surgery), (4) had no documented history of attention deficit hyperactivity disorder or learning disability, (5) did not have baseline tests invalidated per embedded Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) criteria[27] or for suspicion of sandbagging,[52] (6) completed baseline testing $\leq$2 years before postinjury testing consistent with reliability studies,[50] and (7) completed postinjury testing within 3 days of sustaining a concussion.

Lacrosse players were matched to soccer players based on sex and exact year of age to eliminate any effect of age in between-group analyses. Several 2-way analyses of variance (ANOVAs) were conducted to determine differences in sex and sport on demographic factors (Table 1). A 2-way ANOVA for sex and sport on the number of days between baseline and postinjury assessments yielded a significant main effect of sport ($F_{1,220}$ = 9.44, P = .002), with

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TABLE 1
Demographic Characteristics of Male and Female Lacrosse and Soccer Players[a]

	Males (n = 112)		Females (n = 112)			
	Lacrosse Players	Soccer Players	Lacrosse Players	Soccer Players	$F_{3,220}$	*P* Value
Education, years	9.13 ± 1.08	9.30 ± 0.99	9.07 ± 1.08	9.18 ± 1.24	0.46	.71
No. of prior concussions	0.46 ± 0.89	0.46 ± 0.91	0.46 ± 0.80	0.38 ± 0.75	0.70	.55
Days after injury	2.36 ± 0.90	2.55 ± 0.90	2.49 ± 0.96	2.54 ± 0.92	0.51	.68
Days between baseline and postinjury testing	235.12 ± 194.72	113.17 ± 141.54	175.97 ± 194.35	155.81 ± 155.37	4.80	**.003**

[a]Data are reported as mean ± SD. Bolded *P* value indicates statistically significant difference between male and female athletes.

lacrosse players generally exhibiting a greater number of days in between their baseline and postinjury assessments. No effect of sex was found ($F_{1,220}$ = 0.13, *P* = .72) (Table 1), but there was a statistically significant interaction effect between sex and sport ($F_{1,220}$ = 4.84, *P* = .03). Female soccer players had a greater number of days between baseline and postinjury assessments compared with male soccer players, and male lacrosse players had a greater number of days between assessments compared with female lacrosse players.

Seventy-eight percent of athletes listed no recent concussion at baseline testing, and the remaining athletes reported longer than 45 days between their most recent concussion and the completion of baseline testing. Athletes who reported a prior concussion at baseline that occurred within the previous 6 months (n = 11) were compared with the remaining athletes (n = 213) at baseline to evaluate whether performance differences existed. A series of 1-way ANOVAs were conducted with baseline neurocognitive scores and symptoms as dependent variables. Results revealed no significant difference between baseline groups on any outcome variable: Verbal memory ($F_{1,222}$ = 0.11, *P* = .75), Visual memory ($F_{1,222}$ = 0.10, *P* = .75), Visual motor speed ($F_{1,222}$ = 1.60, *P* = .21), Reaction time ($F_{1,222}$ = 2.03, *P* = .16), and Symptoms ($F_{1,222}$ = 0.50, *P* = .48). After all inclusion and exclusion criteria were applied, the final sample consisted of 224 athletes (112 lacrosse players, 112 soccer players) who were matched based on sport, sex, and age (mean [±SD], 15.43 ± 1.09 years; range, 13-17 years).

Procedure

Institutional review board approval of this exempt retrospective study was obtained through Widener University. To assess for the effects of sport-related concussions, a multimodal approach that includes objective measures (eg, neurocognitive testing, vestibular/ocular assessment) is commonly used to ensure full recovery and help avoid a premature return to play.[40,42] Athletes who are reportedly asymptomatic may still demonstrate impairment on objective testing. Computerized neurocognitive testing is a widely used empirical tool that adds value in detecting concussed from nonconcussed athletes.[21,30,46,53,56]

Neurocognitive testing also has prognostic utility during the acute phase to identify athletes expected to have a protracted recovery. Prior research has demonstrated that the use of neurocognitive test cutoff scores in conjunction with reported symptoms within the first 3 days after a concussion improves the sensitivity and specificity of predicting athletes with prolonged recovery times (ie, >14 days).[32,34] As such, prognostic cutoff scores for the neurocognitive composite scores of ImPACT have been established at 75%, 80%, and 85% sensitivity of predicting athletes expected to have a longer recovery time after a concussion.[31] These established cutoffs serve as clinical thresholds that allow practitioners to better prognosticate athletes' recovery time from a concussion within the first few days of their injury.

Athletes in the current study completed ImPACT at baseline (ie, preinjury) and within 3 days of sustaining a concussive injury to assess neurocognitive performance and symptoms. The ImPACT battery is a brief, computerized neurocognitive screening tool that consists of 3 main sections: demographic/injury questionnaires, the Post-Concussion Symptom Scale (PCSS), and a series of 6 neurocognitive test modules; it has been previously identified as a valid[28,53] and reliable[18,50,51] tool for measuring cognitive change after a concussion. Some researchers, however, have questioned the reliability of the measure,[1,2] particularly when conducting group baseline testing.[38,42] The psychometric properties of ImPACT are comparable or better than those of other neurocognitive assessment instruments.[8,45]

The PCSS is a self-report symptom inventory consisting of 22 commonly reported symptoms after a concussion (Table 2). Athletes rate their symptoms on a 7-point Likert scale ranging from 0 (not experiencing the symptom) to 6 (severe). Items are totaled to produce a Total symptom score. The 6 neurocognitive test modules (Word Memory, Design Memory, Xs and Os, Symbol Match, Color Match, and Three Letters) yield 5 summary composite scores (Verbal memory, Visual memory, Visual motor speed, Reaction time, and Impulse control) that are automatically scored by the computer program. Impulse control is often utilized as a measure of effort rather than an assessment of cognitive function.[27,53]

Statistical Analysis

Neurocognitive performance was measured by the ImPACT composite scores: Verbal memory, Visual memory, Visual motor speed, and Reaction time. Symptoms were measured using the Total symptom score. The effects of sex (male vs

TABLE 2
Post-Concussion Symptom Scale (PCSS) Symptoms[25]

Headache	Sensitivity to noise
Nausea	Irritability
Vomiting	Sadness
Balance problems	Nervousness
Dizziness	Feeling more emotional
Fatigue	Numbness or tingling
Trouble falling asleep	Feeling slowed down
Sleeping more than usual	Feeling mentally foggy
Sleeping less than usual	Difficulty concentrating
Drowsiness	Difficulty remembering
Sensitivity to light	Visual problems

female) and sport (lacrosse vs soccer) on neurocognitive performance and symptoms at baseline were evaluated using a multivariate analysis of variance (MANOVA). A 2 × 2 × 2 mixed-factorial MANOVA was conducted with sport and sex (between-participant factors) and time (ie, baseline vs postinjury; within-participant factor) to investigate differences in athletes' neurocognitive performance and postconcussive symptom endorsement. Inherent within MANOVAs, all significant multivariate effects were subsequently explained by univariate analyses.

Postinjury concussion data were further evaluated using independent-samples *t* tests and RCIs. The number of composite scores that exceeded RCI cutoffs from baseline to postinjury at an 80% sensitivity[29] was documented, and sex-based differences were compared using an independent-samples *t* test. A series of chi-square (χ^2) tests were also performed to examine the relationship between sex and the proportion of athletes who were expected to experience a protracted recovery. Data were binarily coded based on whether the athlete demonstrated at least 1 composite score that exceeded established cutoff scores (at 75%, 80%, and 85% sensitivity).[31] The alpha level was set at $P < .05$ for all analyses. Partial eta-squared (η_ρ^2) was used to measure effect sizes (small = 0.01, medium = 0.06, large = 0.14).[7,47]

RESULTS

Baseline Evaluation

The MANOVA revealed significant multivariate effects of sex ($F_{5,216}$ = 2.37, P = .04, η_ρ^2 = .05) and sport ($F_{5,216}$ = 2.79, P = .02, η_ρ^2 = .06) but no interaction effect between sex and sport ($F_{5,216}$ = 0.11, P = .99, η_ρ^2 = .003). Female athletes endorsed significantly greater symptom severity at baseline, but the magnitude of this effect was small (Table 3). Male and female athletes did not statistically differ on any neurocognitive ImPACT composite score at baseline (Table 3). Univariate analyses revealed that soccer players outperformed lacrosse players on Visual memory, which represented a small- to medium-sized effect (Table 4).

Baseline Versus Postinjury Evaluation

A mixed-factorial MANOVA on athletes' baseline versus postinjury performance (time) with sex and sport as between-participant factors yielded significant main effects for time ($F_{5,216}$ = 30.30, $P < .001$, η_ρ^2 = .41), sex ($F_{5,216}$ = 5.43, $P < .001$, η_ρ^2 = .11), and sport ($F_{5,216}$ = 2.36, P = .04, η_ρ^2 = .05). A significant interaction effect was found for time (ie, concussion) × sex ($F_{5,216}$ = 3.86, P = .002, η_ρ^2 = .08). The following interactions were nonsignificant: sport × sex ($F_{5,216}$ = 1.46, P = .21, η_ρ^2 = .03), sport × concussion ($F_{5,216}$ = 1.46, P = .21, η_ρ^2 = .03), or sport × sex × concussion ($F_{5,216}$ = 2.09, P = .07, η_ρ^2 = .05). These results imply that athletes' performance on neurocognitive testing and reported symptoms after a concussion are significantly declined relative to their baseline levels. The performance of female and male athletes on outcome measures after a concussion was significantly different from that at baseline, suggesting that sex likely plays a role in postinjury performance regardless of the type of sport participation. Nonsignificant findings between sport and sex suggest that male soccer and male lacrosse players perform similarly, as do female soccer and female lacrosse players on cognitive testing and symptom reports after a concussion.

Univariate analyses exploring the main effect of time (ie, concussion) yielded significant effects for all ImPACT composite scores and symptoms, with all scores reflecting worse performance after an injury (Table 5); the increase in symptoms after a concussion demonstrated a large effect, while neurocognitive composite score effect sizes ranged from small to medium. Sex yielded a significant main effect for symptoms ($F_{1,220}$ = 19.69, $P < .001$, η_ρ^2 = .08), Verbal memory ($F_{1,220}$ = 4.68, P = .03, η_ρ^2 = .02), Visual memory ($F_{1,220}$ = 11.91, P = .001, η_ρ^2 = .05), and Reaction time ($F_{1,220}$ = 10.42, P = .001, η_ρ^2 = .05), and there was a nonsignificant effect of sex on Visual motor speed ($F_{1,220}$ = 3.55, P = .06, η_ρ^2 = .02). Univariate analyses of the significant interaction of sex and time revealed significant differences for all composite scores, with female athletes consistently performing more poorly (Table 3); however, effect sizes were generally small with the exception of reported symptoms, which demonstrated a medium-sized effect.

The main effect of sport was also explored with univariate analyses but revealed no significant effects on any ImPACT composite score or symptom when comparing baseline to postinjury performance: Verbal memory ($F_{1,220}$ = 0.02, P = .88, $\eta_\rho^2 < .001$), Visual memory ($F_{1,220}$ = 3.62, P = .06, η_ρ^2 = .02), Visual motor speed ($F_{1,220}$ = 0.21, P = .65, η_ρ^2 = .001), Reaction time ($F_{1,220}$ = 1.96, P = .16, η_ρ^2 = .01), and Total symptom score ($F_{1,220}$ = 1.22, P = .27, η_ρ^2 = .01).

Reliable Change Indices

Of the total sample of athletes, 67% demonstrated at least 1 (of 5 possible) declined RCI scores on postinjury neurocognitive testing and/or symptoms (median, 1; range, 0-5). A comparison of the mean number of exceeded RCIs

TABLE 3
Univariate Analysis of the Effect of Sex on Baseline Testing and the Interaction Effect of Concussion and Sex on Cognitive Performance and Symptoms When Lacrosse and Soccer Athletes Are Combined[a]

	Baseline					After Injury		Sex × Concussion Interaction Effect		
	Male	Female	$F_{1,220}$	*P* Value	η_ρ^2	Male	Female	$F_{1,220}$	*P* Value	η_ρ^2
Verbal memory	87.04 ± 7.89	87.19 ± 8.78	0.02	.89	<.001	87.38 ± 11.23	82.38 ± 13.56	8.95	.003[b]	.04
Visual memory	79.12 ± 9.32	77.63 ± 9.75	1.42	.24	.01	77.96 ± 13.31	70.57 ± 14.37	10.15	.002[b]	.04
Visual motor speed	39.61 ± 6.46	39.28 ± 6.19	0.15	.70	.001	39.40 ± 7.97	36.53 ± 8.82	5.89	.02[b]	.03
Reaction time[c]	0.57 ± 0.08	0.59 ± 0.07	3.32	.07	.02	0.59 ± 0.10	0.64 ± 0.15	4.23	.04[b]	.02
Symptoms[c]	1.92 ± 2.81	3.11 ± 3.73	7.20	.01[b]	.03	10.04 ± 12.11	18.29 ± 17.29	13.85	<.001[b]	.06

[a]Data are reported as mean ± SD.
[b]Statistically significant ($P < .05$).
[c]Higher values reflect a worse performance.

TABLE 4
Univariate Analysis of the Main Effect of Sport on Baseline Testing[a]

	Lacrosse	Soccer	$F_{1,220}$	*P* Value	η_ρ^2
Verbal memory	86.08 ± 8.04	88.14 ± 8.52	3.44	.07	.02
Visual memory	76.35 ± 9.40	80.39 ± 9.30	10.46	.001[b]	.05
Visual motor speed	38.91 ± 5.92	39.98 ± 6.67	1.60	.21	.01
Reaction time[c]	0.58 ± 0.08	0.58 ± 0.07	0.36	.55	.002
Symptoms[c]	2.54 ± 3.36	2.48 ± 3.34	0.02	.89	<.001

[a]Data are reported as mean ± SD.
[b]Statistically significant difference between lacrosse and soccer ($P < .05$).
[c]Higher values reflect a worse performance.

TABLE 5
Univariate Analysis of the Main Effect of Concussion on All Athletes' Cognitive Performance and Symptoms[a]

	Baseline	After Injury	$F_{1,220}$	*P* Value	η_ρ^2
Verbal memory	87.11 ± 8.33	84.88 ± 12.67	6.74	.01[b]	.03
Visual memory	78.37 ± 9.55	74.26 ± 14.31	19.73	<.001[b]	.08
Visual motor speed	39.44 ± 6.31	37.97 ± 8.51	7.92	.01[b]	.04
Reaction time[c]	0.58 ± 0.07	0.62 ± 0.13	17.15	<.001[b]	.07
Symptoms[c]	2.51 ± 3.34	14.17 ± 15.46	150.93	<.001[b]	.41

[a]Data are reported as mean ± SD.
[b]Statistically significant difference between baseline and after injury ($P < .05$).
[c]Higher values reflect a worse performance.

revealed that female athletes had a significantly greater number of exceeded RCI cutoffs compared with male athletes (1.92 ± 1.62 vs 1.17 ± 1.37, respectively; $t(216.16) = -3.732$, $P < .001$). A total of 59% of male athletes and 74% of female athletes demonstrated at least 1 RCI decline.

Protracted Recovery

Protracted recovery refers to those athletes who do not return to their baseline level of functioning within the typical 7- to 10-day recovery period expected for concussed adolescents.[9,39] Prognostic cutoff scores for ImPACT have been established for identifying, during the acute phase of an injury, those athletes who will go on to experience a protracted recovery. These cutoff scores have been established at 75%, 80%, and 85% sensitivity for predicting those athletes whose recovery will take longer than 2 weeks.[31]

A chi-square test of independence yielded a significant relationship between sex and protracted recovery at each of the sensitivity cutoffs: 75% sensitivity (χ^2 (1, N = 224) = 9.43, $P = .002$), 80% sensitivity (χ^2 (1, N = 224) = 11.21, $P = .001$), and 85% sensitivity (χ^2 (1, N = 224) = 8.00, $P = .01$). A significantly higher proportion of female athletes demonstrated postinjury neurocognitive scores reflective of protracted recovery (Table 6).

TABLE 6
Chi-square Analysis of Predicted Protracted Recovery in Male Versus Female Athletes[a]

Sex	75% Sensitivity	80% Sensitivity	85% Sensitivity
Male (n = 112)			
Protracted recovery	15 (13.4)	10 (8.9)	7 (6.3)
Not present	97 (86.6)	102 (91.1)	105 (93.8)
Female (n = 112)			
Protracted recovery	34 (30.4)	29 (25.9)	21 (18.8)
Not present	78 (69.6)	83 (74.1)	91 (81.3)
χ^2 test	9.43	11.21	8.00
P value	.002[b]	.001[b]	.01[b]

[a]Data are reported as n (%).
[b]Statistically significant difference between male and female athletes ($P < .05$).

DISCUSSION

The current study aimed to explore the effect of a concussive injury on adolescent male (n = 112) and female (n = 112) lacrosse players. Soccer players were also included in the study and matched to lacrosse players based on sport, age, and sex in an attempt to control for confounding sport differences in male and female versions of lacrosse. Athletes underwent baseline and acute postconcussion (ie, within 3 days of injury) evaluations using computerized neurocognitive testing and symptom reports. The results of this study were consistent with prior literature suggesting that female sex may be a modifier of concussion outcomes on neurocognitive testing and symptom reports among both soccer and lacrosse players.

Baseline analyses before the injury found that male and female athletes performed similarly across all neurocognitive indices (Table 3). Although there were no differences in cognitive scores, female athletes reported a significantly greater number of symptoms before the injury, albeit this difference only represented a small-sized effect. Greater symptom endorsement among female athletes at baseline has been well documented in the literature and may be related to sociocultural factors and/or physiological differences among male and female athletes.[13-15,17,49,58] Recent research speculates that hormonal fluctuations occurring through phases of the female menstrual cycle may mediate female athletes' endorsement of symptoms at baseline, as many hormone-related symptoms overlap with those expected after a concussion (eg, headache, fatigue, emotional lability).[57] Comparison of the baseline profile of soccer and lacrosse players was similar, with the exception of soccer players outperforming lacrosse players on tasks of visual memory.

A postinjury evaluation was conducted by comparing athletes' baseline and postinjury neurocognitive performance and symptoms using a repeated-measures MANOVA with sport and sex as between-participant factors. Results yielded a significant large overall effect of a concussion with athletes' performance declining on all cognitive and symptom measures after an injury, regardless of sport type (Table 4). This is consistent with prior studies demonstrating that athletes experience a decline on objective cognitive testing and endorse a greater number of somatic, cognitive, emotional, and sleep-related symptoms after an injury.[40,41,56] These cognitive changes and symptoms are typically transient in nature and expected to return to baseline.[9,15,39] The neurocognitive performance and symptom profiles of lacrosse and soccer players after a concussion were similar across each neurocognitive and symptom outcome measure.

An exploration of sex-based differences revealed a significant medium-to-large main effect and interaction effect with time (ie, concussion). Female athletes performed significantly worse than male athletes across all neurocognitive measures and reported more symptoms after a concussion. The significant interaction effect between sex and concussion indicates that the degree at which female athletes' performance and symptoms worsened relative to their baseline levels was of a greater severity (ie, steeper slope) relative to male athletes. The size of the difference in male and female scores was generally small, however, suggesting that these statistical findings may not be apparent in a clinical context. To further evaluate the clinical utility of these findings and speculate the recovery trajectory among male and female athletes, athletes' postinjury performance was compared with established clinical cutoff scores. Female athletes in this study also demonstrated a greater number of scores exceeding RCI cutoffs[27] as well as a higher frequency of postinjury scores predictive of a prolonged recovery time when compared with male athletes. This suggests that during the acute stages of a concussion, female athletes exhibit a statistical trend of worse cognitive and symptom scores compared with male athletes and are more likely to demonstrate scores indicative of a longer recovery phase. Again, caution is warranted in applying these results clinically, given only small-to-medium effect sizes observed on outcome measures between sexes. The cross-sectional nature of these data also prevents us from understanding the individualized trajectory of male and female athletes over time. It is possible that female athletes exhibit signs of worse concussion symptoms during the acute phase but still recover within the same time frame as male athletes.

Previous research on athlete sex as a modifier of concussions has yielded inconsistent findings. Some studies have similarly found that female athletes demonstrate poorer cognitive profiles and more symptoms,[5,10,12,16,49] while other studies have found no sex-based differences.[13,22,59] The reason for inconsistent findings on the effect of sex in concussion recovery is unclear but may be related to methodological differences between studies. Unlike the current study, some studies did not apply strict criteria for the number of days tested after the injury and/or control for baseline performance.[10,12,58] Most adolescent athletes are expected to recover from a concussion within 7 to 10 days of the injury, and analyzing acute effects beyond this time frame may not capture the cognitive and symptom changes observed in our study.[9,39] Other studies included older collegiate populations rather than adolescent athletes, which also may explain disparities.[10,16] The physiological[11,19,20,48,54] and psychological[17,23] responses to mild sport-related head injuries among adolescent male and female athletes require further exploration to identify underlying mechanisms contributing to sex-based differences. As mentioned, fluctuations in female hormones through the menstrual cycle may be a potential mechanism that alters their response to a concussive injury.[57]

There are several implications related to the current study findings. First, adolescent athletes endorsed a greater number of symptoms and had lowered cognitive profiles during the first few days after a concussion relative to their baseline assessment. It is recommended that as athletes' overt symptoms resolve, cognition and other objective markers of recovery be tracked over time[3] using a multimodal approach to ensure a return to baseline before full re-engagement in athletic activity. Specifically, objective testing may be most valuable in instances when athletes are reportedly asymptomatic but still exhibiting signs of a concussion.[49,56] Also, female adolescents statistically appear more vulnerable to the effects of an acute concussion and may be at an increased likelihood of protracted recovery. A longer length of recovery puts female athletes at a greater risk of premature return to play. Practitioners managing sport concussions should be cautious in applying research from concussed male athletes' patterns of recovery to concussed female athletes, as they may demonstrate different patterns of performance during the acute phase of the injury. Future studies should verify the current study results prospectively in a longitudinal design with multiple objective measures as well as explore whether male and female athletes differ in their responses to treatment for a concussion.

This study is not without limitations. Given the retrospective nature of data collection, it is unknown whether environmental conditions were monitored during athletes' testing, which could have impacted their performance. Strict exclusion criteria were applied to minimize tests indicative of poor performance at baseline. All demographic and injury information was collected through embedded questions within ImPACT rather than through clinical interviews or a review of medical records, which may have led to inaccurate reporting, given that this information was unable to be externally verified. The retrospective nature of data collection also resulted in the inclusion of some athletes who completed their baseline testing over a year before their postinjury evaluation. Although the reliability of ImPACT has been demonstrated over a 2-year period for collegiate populations,[50] the maturational brain changes that occur during adolescence may have impacted athletes' neurocognitive test performance. Because adolescent athletes' neurocognitive performance improves with age,[25] it may have mitigated the potential declines in cognitive performance after a concussion in the current study. Lastly, adolescent athletes often play multiple sports, and therefore, soccer and lacrosse participation are not mutually exclusive. Despite these limitations, the results of the current study are consistent with previous research on sex-based differences in concussions. This was the first study to specifically explore neurocognitive performance among lacrosse players on ImPACT, and it provides a foundation for future studies on concussions in this growing population of athletes.

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