ORIGINAL ARTICLE

Sex differences in baseline neuropsychological function and concussion symptoms of collegiate athletes

T Covassin, C B Swanik, M Sachs, Z Kendrick, P Schatz, E Zillmer, C Kaminaris

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See end of article for authors' affiliations

Correspondence to: Tracey Covassin, Department of Kinesiology, Michigan State University, East Lansing, Michigan, USA; covassin@msu.edu

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Objective: To investigate sex differences in baseline neuropsychological function and concussion symptoms between male and female collegiate athletes.
Methods: A post-test only design was used to examine baseline neuropsychological test scores and concussion symptoms. A total of 1209 NCAA Division I collegiate athletes from five northeastern universities in the USA completed a baseline ImPACT test. ImPACT, a computerised neuropsychological test battery, was administered during an athlete's pre-season.
Results: Female athletes performed significantly better than male athletes on baseline verbal memory scores (p = 0.001), while male athletes performed significantly better than female athletes on baseline visual memory scores (p = 0.001). Female athletes endorsed a significant number of mild baseline symptoms as compared to male athletes.
Conclusions: Male and female athletes exhibit differences on baseline neuropsychological test performance and concussion symptoms.

Sex differences in cognitive performance have been reported for verbal memory,[1–4] perceptual motor speed[2] and visuospatial tasks.[2 4] Moreover, researchers have shown that brain function differs between the sexes.[1–4] Weiss *et al*[2] found that females perform better on verbal memory and perceptual motor speed compared to males. Conversely, males perform better on visuospatial tests than females. Therefore, it is important to determine if collegiate male and female athletes exhibit differences in baseline neuropsychological function and symptoms. If female and male athletes' neurocognitive abilities vary on baseline test scores, then it is possible that the athletes may also perform differently on post-concussion testing.

Approximately 300 000 sport-related concussions are reported each year.[5] Over the past two decades, sports medicine professionals have stressed the importance of baseline neuropsychological testing of athletes for comparison after concussion.[6–11] However, very few researchers have explored sex differences in baseline neuropsychological function and concussion symptoms among collegiate athletes.[2 12] Baseline neuropsychological testing is useful for evaluating concussion. First, post-concussion decreases in performance from baseline testing may provide a more subtle evaluation[13] of neuropsychological impairment. Second, individual performance may vary on tests of attention and concentration, memory, information processing and reaction time. If it is not known how an individual athlete performed before sustaining a concussion, it is difficult to ascertain whether their post-concussion level of test performance is due to the effects of the concussion or to individual variability. As a result, comparisons between the concussed athlete and a normative group are difficult. Finally, baseline neuropsychological tests may be used as a tool for determining concussion resolution together with clinical evaluation for readiness to return to play.[11] Athletes should not return to participation until their neuropsychological test scores are equal to or better than the baseline test scores and they do not display any signs and symptoms of concussion.[14] For these reasons, baseline neuropsychological test scores should provide for more sensitive and accurate concussion evaluation and detection and may reduce the risks of cumulative neurocognitive dysfunction.[15] Therefore, the purpose of this study was to determine if sex differences exist in baseline neuropsychological function and concussion symptoms.

METHODS

Study design

A post-test only design was used to compare neuropsychological test scores and concussion symptoms. The independent variable was sex. The dependent variables were verbal and visual memory, reaction time and processing speed composite scores, as well as total symptom scores.

Subjects

The subjects were American collegiate athletes participating in baseball, basketball, cheerleading, fencing, figure skating, football, gymnastics, lacrosse, soccer, softball, volleyball and wrestling (see table 1). The athletes were from five northeastern universities representing the states of Delaware, New Jersey, and Pennsylvania and were practicing and competing in the 2002–2003 and 2003–2004 academic seasons. A total of 1209 athletes volunteered to participate in the study with a mean of 1.24 years of collegiate experience. Sex distribution was reasonably consistent with the athletic population from each institution, with 651 males (height 184$\pm$45.17 cm, weight 70.85$\pm$7.00 lbs) and 558 females (height 136.2$\pm$27.05 cm, weight 65.4$\pm$6.53 lbs) participating in the study.

Outcome measures

ImPACT version 2.0 was used for the study.[16] The ImPACT instrument is a computer-based program used to assess neurocognitive function and concussion symptoms. It consists of six neurocognitive tests that evaluate attention processes, verbal recognition memory, visual working memory, visual processing speed, reaction time, numerical sequencing ability and learning.[17] Test-retest reliability for ImPACT was assessed over 8 days across four administrations,

Table 1 Baseline sports information on study participants

Sport	Number	Percent
Baseball	82	6.8
Cheerleading	65	5.4
Football	179	14.8
Field hockey	81	6.7
Figure skating	20	1.7
Men's basketball	84	6.9
Men's gymnastics	18	1.5
Men's lacrosse	84	6.9
Men's soccer	145	12.0
Softball	71	5.9
Women's basketball	85	7.1
Women's fencing	10	.8
Women's gymnastics	37	3.1
Women's lacrosse	53	4.4
Wrestling	59	4.9
Women's soccer	94	7.8
Women's volleyball	42	3.5

yielding correlation coefficients ranging from 0.66 to 0.85 for the verbal memory index, 0.75 to 0.88 for the processing speed, and 0.62 to 0.66 for the reaction time.[18] Using reliable change indices, repeated administrations over a 2 week period revealed no practice effects.[19] Correlations between the ImPACT visual and verbal memory composites with the Brief Visual Spatial Memory Test-Revised total score ($r = 0.50$) and the delayed recall score ($r = 0.85$) have been established[20]; the processing speed composite was shown to correlate with Trailmaking Tests A ($r = -0.49$) and B ($r = -0.60$), and the Symbol-Digit Modalities test ($r = 0.68$). Schatz and colleagues[21] documented a combined sensitivity of 81.9% for ImPACT indices and total symptom score, and a specificity of 89.4%; positive likelihood ratio was approximately 8:1 and negative likelihood ration was 2:1. Validity studies did not examine sex differences, nor was ImPACT developed to minimise sex differences.

Protocol

Institutional Review Board approval for the research study was granted from each participating university, and written informed consent was obtained from all team physicians, athletic directors, athletes and certified athletic trainers. Athletes reported to their own institution's athletic training room and then were taken to the computer laboratory by the researchers and explained the test procedures. Athletes completed the ImPACT neuropsychological test battery on a computer, which required approximately 30 min.

Data analysis

The ImPACT yields individual scores as well as composite scores for verbal memory, visual memory, motor processing speed and reaction time. Higher scores on verbal and visual memory and motor processing speed indicate a better performance. Verbal and visual memory scores are presented as a percentage of 100 and motor processing speed as a number composite score. The number composite score for motor processing speed is comprised of the average of the following test scores: (i) X's and O's–total correct (interference)/4; and (ii) three-letters-average counted correctly multiplied by 3. A lower score on reaction time indicates a better performance. All reaction time scores are presented in seconds. The ImPACT also yields individual scores for concussion symptoms. Athletes are asked to indicate if they are currently experiencing any of 22 concussion symptoms. The concussion symptoms are rated on a 7-point Likert scale, with 0 indicating not experiencing and 6 indicating severe.

A one-way multiple analysis of variance (MANOVA) was performed on verbal and visual memory, reaction time, and motor processing speed with sex as the between factor. The level of significance was set at $p = 0.05$. Another one-way MANOVA was performed on all the concussion symptoms with sex as the between factor. A minimum effect size of $\eta^2 = 0.25$ between subjects and a probability level of 0.05 would require 25 subjects in each group for a statistical power of $p = 0.80$.[22] All analyses were conducted using the Statistical Package for the Social Sciences version 11.1 (SPSS Inc, Chicago, USA).

RESULTS

Baseline neuropsychological test scores

MANOVA (Hotelling's trace) revealed a significant multivariate effect of sex on cognitive performance ($F_{4,1204} = 19.08$, $p = 0.001$; $h^2 = 0.06$). Subsequent univariate ANOVAs revealed that female athletes ($n = 558$) performed significantly better than male athletes on baseline verbal memory test scores ($F_{1,1207} = 35.6$, $p = 0.001$; $d = 0.40$). Male athletes ($n = 613$) performed significantly better than female athletes on baseline visual memory test scores ($F_{1,1207} = 10.5$, $p = 0.001$; $d = 0.23$). There were no significant differences on baseline motor processing speed and reaction time test scores (see table 2).

Baseline concussion symptoms

MANOVA (Wilks' lambda) revealed a significant multivariate effect of sex on symptoms endorsed ($F_{22,1186} = 4.63$, $p = 0.001$; $h^2 = 0.08$). Subsequent univariate ANOVAs ($df = 1, 1207$) revealed that symptoms endorsed by female athletes resulted in significantly higher mean symptom scores for the following symptoms, as compared to male athletes: headache ($F = 20.4$, $p = 0.001$; $d = 0.25$), nausea ($F = 7.9$, $p = 0.005$; $d = 0.16$), fatigue ($F = 7.3$, $p = 0.007$; $d = 0.16$), sleeping more than usual ($F = 6.2$, $p = 0.01$; $d = 0.14$), drowsiness ($F = 6.2$, $p = 0.01$; $d = 0.14$), sensitivity to light ($F = 8.9$, $p = 0.003$; $d = 0.17$), sensitivity to noise ($F = 6.6$, $p = 0.01$; $d = 0.15$), sadness ($F = 14.9$, $p = 0.001$; $d = 0.22$), nervousness ($F_{1,1207} = 11.7$, $p = 0.001$; $d = 0.21$), feeling more emotional ($F = 51.3$, $p = 0.001$; $d = 0.40$), difficulty concentrating ($F = 10.4$, $p = 0.002$; $d = 0.18$), visual problems ($F = 4.9$, $p = 0.03$; $d = 0.13$), and total symptom scores ($F = 17.4$, $p = 0.001$; $d = 0.24$). Refer to table 3 for means, standard deviations, ANOVA results and effect sizes.

As mean symptom scores did not reflect sex differences in symptom severity or likelihood of endorsing symptoms, Likert-scale symptom scores were recoded into a nominal/ordinal variable: none (scores of 0), mild (scores of 1, 2), moderate (scores of 3, 4) and severe (scores of 5, 6). χ^2 analyses ($df = 3$; see table 4) revealed a significantly higher likelihood of symptom endorsement by female athletes for the following symptoms: headache ($\chi^2 = 21.8$, $p = 0.001$; $V = 0.13$), nausea ($\chi^2 = 8.2$, $p = 0.04$; $V = 0.08$), fatigue ($\chi^2 = 10.6$, $p = 0.014$; $V = 0.09$), trouble falling asleep ($\chi^2 = 9.5$, $p = 0.024$; $V = 0.09$), sleeping more than usual ($\chi^2 = 8.3$, $p = 0.03$; $V = 0.09$), sleeping less than usual ($\chi^2 = 8.2$, $p = 0.04$; $V = 0.08$), drowsiness ($\chi^2 = 5.5$, $p = 0.05$; $V = 0.08$), sensitive to light ($\chi^2 = 10.9$, $p = 0.012$; $V = 0.10$), sensitive to noise ($\chi^2 = 10.7$, $p = 0.013$; $V = 0.09$), irritability ($\chi^2 = 12.2$, $p = 0.007$; $V = 0.10$), sadness ($\chi^2 = 16.5$, $p = 0.001$; $V = 0.12$), nervousness ($\chi^2 = 12.7$, $p = 0.005$; $V = 0.10$), feeling more emotional ($\chi^2 = 51.1$, $p = 0.001$; $V = 0.21$), difficulty concentrating ($\chi^2 = 9.4$, $p = 0.025$; $V = 0.09$), and total symptom scores ($\chi^2 = 12.3$, $p = 0.006$; $V = 0.10$).

Table 2 All baseline neuropsychological test scores (n = 1209)

Test	Gender	Mean	SD	F	p	d†
Verbal memory	Male	0.82	0.10	35.6	0.001**	0.40
	Female	0.86	0.10			
Visual memory	Male	0.74	0.13	10.5	0.001**	0.23
	Female	0.71	0.13			
Processing speed	Male	38.8	7.24	0.36	0.55	0.03
	Female	39.0	7.08			
Reaction time	Male	0.55	0.083	0.04	0.85	0.00
	Female	0.55	0.074			

*Significant at the 0.001 level; †Cohen's d.

DISCUSSION

The overall results of this study revealed sex differences in baseline neuropsychological function and concussion symptoms. According to our findings, female athletes performed significantly better on baseline verbal memory compared to male athletes, while male athletes performed significantly better on baseline visual memory compared to female athletes. These results are consistent with Weiss *et al*[2] who suggest that females perform better on verbal memory compared to males, while males respond to visual information better than females. Similarly, Barr[12] reported that female athletes performed better on verbal initiation compared to male athletes.

Females may perform better on baseline verbal memory scores due to increased levels of oestrogen compared to males. Maki *et al*[22] reported that females who received hormone replacement therapy exhibited better verbal memory test scores than those who did not. Both male and female athletes endorsed a wide range of mild symptoms at baseline, with 68% of male athletes and 76% of female athletes endorsing at least one symptom. Our findings

Table 3 All baseline concussion symptoms by sex (n = 1209)

Symptom	Sex	Mean	SD	F	p	d†
Headache	Male	0.45	0.94	20.4	0.001***	0.25
	Female	0.73	1.24			
Nausea	Male	0.15	0.53	7.9	0.005**	0.16
	Female	0.25	0.69			
Vomiting	Male	0.05	0.32	0.99	0.32	0.04
	Female	0.04	0.23			
Balance problems	Male	0.17	0.61	0.37	0.54	0.03
	Female	0.19	0.68			
Dizziness	Male	0.21	0.61	1.7	0.19	0.07
	Female	0.26	0.75			
Fatigue	Male	0.87	1.28	7.3	0.007**	0.16
	Female	1.08	1.35			
Trouble falling asleep	Male	0.58	1.24	2.6	0.10	0.10
	Female	0.70	1.28			
Sleeping more than usual	Male	0.29	0.85	6.2	0.01**	0.14
	Female	0.42	1.03			
Sleeping less than usual	Male	0.66	1.29	1.48	0.22	0.07
	Female	0.75	1.28			
Drowsiness	Male	0.53	1.06	6.2	0.01**	0.14
	Female	0.69	1.19			
Sensitive to light	Male	0.21	0.70	8.9	0.003**	0.17
	Female	0.35	0.90			
Sensitive to noise	Male	0.15	0.64	6.6	0.01**	0.15
	Female	0.26	0.82			
Irritability	Male	0.43	1.03	3.3	0.07	0.08
	Female	0.54	1.09			
Sadness	Male	0.25	0.75	14.9	0.001***	0.22
	Female	0.45	1.05			
Nervousness	Male	0.31	0.82	11.7	0.001***	0.21
	Female	0.52	1.18			
Feeling more emotional	Male	0.25	0.75	51.3	0.001***	0.40
	Female	0.68	1.31			
Numbness	Male	0.08	0.41	0.09	0.76	0.02
	Female	0.09	0.51			
Feeling slowed down	Male	0.42	0.97	1.56	0.21	0.07
	Female	0.49	0.98			
Feeling mentally foggy	Male	0.35	0.87	0.34	0.56	0.03
	Female	0.38	1.04			
Difficulty concentrating	Male	0.48	1.03	10.4	0.002**	0.18
	Female	0.69	1.26			
Difficulty remembering	Male	0.32	0.89	3.6	0.06	0.11
	Female	0.43	1.04			
Visual problems	Male	0.11	0.49	4.9	0.03**	0.13
	Female	0.18	0.61			
Total symptoms‡	Male	7.34	11.01	17.4	0.001***	0.24
	Female	10.16	12.47			

*Significant at the 0.05 level; **significant at the 0.01 level; *** significant at the 0.001 level.
†Cohen's d; ‡not included in MANOVA.

Table 4 Percentage of baseline concussion symptoms by sex (n = 1209)

Symptom	Sex	% (mild)	% (moderate)	% (severe)	% (total)	χ^2 (df = 3)	p	V†
Headache	Male	18.9	5.4	0.3	24.6	21.8	0.001**	0.13
	Female	22.9	9.3	2.2	34.4			
Nausea	Male	8.3	1.2	0.2	9.7	8.2	0.04*	0.08
	Female	13.1	1.8	0.2	15.1			
Vomiting	Male	3.4	0.3	0.0	3.7	1.8	0.40	0.04
	Female	3.0	0.0	0.0	3.0			
Balance problems	Male	8.1	1.4	0.3	9.8	0.4	0.95	0.02
	Female	7.9	1.8	0.4	10.0			
Dizziness	Male	11.2	1.7	0.2	13.1	2.0	0.56	0.04
	Female	11.6	2.7	0.4	14.7			
Fatigue	Male	25.7	13.4	1.4	40.4	10.6	0.014*	0.09
	Female	29.2	18.5	0.9	48.6			
Trouble falling asleep	Male	15.4	6.5	2.6	24.4	9.5	0.024*	0.09
	Female	17.9	10.4	1.6	29.9			
Sleeping more than usual	Male	8.6	4.5	0.5	13.5	8.9	0.03*	0.09
	Female	12.5	5.0	1.4	19.0			
Sleeping less than usual	Male	17.4	7.7	2.8	27.8	8.2	0.04*	0.08
	Female	18.6	12.0	1.8	32.4			
Drowsiness	Male	18.9	6.3	0.9	26.1	5.5	0.05*	0.08
	Female	21.0	10.0	1.3	32.3			
Sensitive to light	Male	8.6	2.2	0.5	11.2	10.9	0.012*	0.10
	Female	12.9	4.1	0.7	17.7			
Sensitive to noise	Male	6.6	1.1	0.6	8.3	10.7	0.013*	0.09
	Female	8.6	3.6	0.5	12.7			
Irritability	Male	12.7	5.4	1.2	19.4	12.2	0.007**	0.10
	Female	20.1	5.2	1.4	26.7			
Sadness	Male	11.5	1.7	0.6	13.8	16.5	0.001***	0.12
	Female	17.0	3.2	2.0	22.2			
Nervousness	Male	13.7	3.2	0.6	17.5	12.7	0.005**	0.10
	Female	16.8	4.3	2.7	20.4			
Feeling more emotional	Male	10.8	2.2	0.5	13.4	51.1	0.001***	0.21
	Female	18.5	7.9	2.5	28.9			
Numbness	Male	4.3	0.6	0.0	4.9	3.0	0.39	0.05
	Female	3.4	0.7	0.4	4.5			
Feeling slowed down	Male	16.1	4.9	0.8	21.8	6.3	0.10	0.07
	Female	21.3	5.2	0.4	26.9			
Feeling mentally foggy	Male	14.0	4.0	0.5	18.4	0.6	0.91	0.02
	Female	14.7	4.7	0.4	19.7			
Difficulty concentrating	Male	18.1	5.4	1.2	24.7	9.4	0.025*	0.09
	Female	21.0	8.6	2.2	31.7			
Difficulty remembering	Male	12.4	3.1	0.9	16.4	3.3	0.35	0.05
	Female	14.0	3.9	1.8	19.7			
Visual problems	Male	6.0	0.8	0.3	7.1	6.7	0.08	0.07
	Female	9.9	1.1	0.4	11.3			
Total symptoms***	Male	66.2	1.4	0.2	67.8	12.3	0.006**	0.10
	Female	73.5	2.5	0.0	76.0			

*Significant at the 0.05 level; **significant at the 0.01 level; ***significant at the 0.001 level.
†Cramer's V (measure of effect size).

revealed sex differences in baseline concussion symptoms. Small (effect size) but significant differences were seen in endorsement of mild degrees (for example, 1–2 on a 0–6 scale) of headache, fatigue, sleep difficulty, irritability, sadness, nervousness, feeling more emotional, feeling slowed down and difficulty concentrating. Further, at baseline, approximately 30–50% of the participants endorsed mild degrees of fatigue, sleep difficulty, drowsiness and difficulty concentrating. It is important to note that nearly all symptoms endorsed were mild in nature, with only 2–3% of participants endorsing any severe symptom (for example, 5–6 on a 0–6 scale). Baseline differences in symptom endorsement may be accounted for by numerous factors. For example, fatigue, drowsiness, and sleeping more than usual may be attributed to over training, time of season or lack of rest. Headache, nausea, sadness, and feeling more emotional may be attributed to female athletes' menstrual cycle. However, these variables were not addressed in this study and warrant further investigation. Thus, sex differences in baseline symptom endorsing illustrate the importance of individual baseline evaluation which may help clinicians determine if an athlete is symptomatic as a result of the concussion or individual sex variability.

The present study shows that male and female athletes differ on baseline test measures. Normative data for ImPACT have been gender-corrected,[23] so these results, in part, serve as a replication and external validation of the test developer's norms. However, it is recommended that baseline testing continues, to allow athletes to serve as their own controls when comparing baseline and post-concussion data. The current study demonstrates that athletes' performance does vary on the basis of gender on tests of visual and verbal memory, with significant between-groups differences and small-to-medium effect sizes, respectively. Furthermore, the athletes, as a group, displayed considerable variation in their performance on baseline test measures. Therefore, if an individual player's performance before sustaining a concussion is not known, it is difficult to ascertain whether his/her level of performance is due to the effects of the concussion or to secondary effects.

In conclusion, significant sex differences were found in baseline neuropsychological function and concussion symptoms, with small-to-medium effect sizes. As male and female athletes exhibit sex differences at baseline, they may also demonstrate sex differences on post-concussion test scores, and clinicians need to be aware of these differences,

What is already known on this topic

- Sex differences in cognitive performance have been reported for verbal memory, perceptual motor speed and visuospatial tasks.
- Normative data for ImPACT, a computerised neuropsychological test battery, have been gender-corrected.

What this study adds

- The present study shows that male and female athletes differ on baseline tests of visual and verbal memory.
- It is recommended that baseline testing continues to allow athletes to serve as their own controls when comparing baseline and post-concussion data.

especially when evaluating post-concussion data in the absence of a baseline assessment.

Authors' affiliations

T Covassin, Department of Kinesiology, Michigan State University, East Lansing, Michigan, USA

C B Swanik, Department of Health, Nutrition, and Exercise Sciences, University of Delaware, Newark, Delaware, USA

M Sachs, Z Kendrick, Department of Kinesiology, Temple University, Philadelphia, Pennsylvania, USA

P Schatz, Department of Psychology, Saint Joseph's University, Philadelphia

E Zillmer, C Kaminaris, Department of Psychology, Drexel University, Philadelphia

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COMMENTARY

Without question, there are small but meaningful differences between men and women on variables that are relevant to outcome from concussion in sports. For example, women and men differ on some neurocognitive abilities and they differ in the way they experience and report subjective symptoms. More research is needed on the effects of a number of demographic and clinical variables, such as sex, ethnicity, learning disabilities, ADHD, and substance use on outcome measures used in sport concussion research.

G Iverson
University of British Columbia, Canada; giverson@interchange.ubc.ca

COMMENTARY

This study is clearly presented, and important. The authors address a topic that is timely and relevant in sports medicine. In a large sample of 1209 collegiate male and female athletes' baseline neuropsychological function and concussion symptoms, the present study illustrates that male and female athletes differ on baseline neuropsychological test measures. Variability, particularly on verbal and visual memory scores between genders indicates a need to compare an athlete with his/her own baseline and not a normative group when making field decisions regarding post-concussion status and return to participation. Secondly, female athletes reported 13 out of 22 baseline concussion symptoms higher compared to male athletes. However, the small difference in concussion symptom scores may indicate that the significance found may be due to the very large sample size and may not be clinically relevant. Also, symptoms were self-reported by each athlete. Therefore, significant gender differences may be due, in part, to an athlete's willingness to report symptoms. Further study is needed to determine if male and female athletes exhibit differences on post-concussion symptoms and neuropsychological function.

D J Stearne
West Chester University, Pennsylvania, USA; dstearne@wcupa.edu