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Sport and Team Differences on Baseline Measures of Sport-Related Concussion

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Context: With the advent of the National Collegiate Athletic Association's (NCAA's) mandating the presence and practice of concussion-management plans in collegiate athletic programs, institutions will consider potential approaches for concussion management, including both baseline and normative comparison approaches.

Objective: To examine sport and team differences in baseline performance on a computer-based neurocognitive measure and 2 standard sideline measures of cognition and balance and to determine the potential effect of premorbid factors sex and height on baseline performance.

Design: Cross-sectional study.

Setting: University laboratory.

Patients or Other Participants: A total of 437 NCAA Division II student-athletes (males = 273, females = 164; age = 19.61 ± 1.64 years, height = 69.89 ± 4.04 inches [177.52 ± 10.26 cm]) were recruited during mandatory preseason testing conducted in a concussion-management program.

Main Outcome Measure(s): The computerized Concussion Resolution Index (CRI), the Standardized Assessment of Concussion (Form A; SAC), and the Balance Error Scoring System (BESS).

Results: Players on the men's basketball team tended to perform worse on the baseline measures, whereas soccer players tended to perform better. We found a difference in total BESS scores between these sports ($P = .002$). We saw a difference between sports on the hard-surface portion of the BESS ($F_{6,347} = 3.33$, $P = .003$, $\eta_p^2 = 0.05$). No sport, team, or sex differences were found with SAC scores ($P > .05$). We noted differences between sports and teams in the CRI indices, with basketball, particularly the men's team, performing worse than soccer ($P < .001$) and softball/baseball ($P = .03$). When sex and height were considered as possible sources of variation in BESS and CRI team or sport differences, height was a covariate for the team ($F_{1,385} = 5.109$, $P = .02$, $\eta_p^2 = 0.013$) and sport ($F_{1,326} = 11.212$, $P = .001$, $\eta_p^2 = 0.033$) analyses, but the interaction of sex and sport on CRI indices was not significant in any test ($P > .05$).

Conclusions: Given that differences in neurocognitive functioning and performance among sports and teams exist, the comparison of posttraumatic and baseline assessment may lead to more accurate diagnoses of concussion and safer return-to-participation decision making than the use of normative comparisons.

Key Words: traumatic brain injuries, baseline assessment, Concussion Resolution Index, Standardized Assessment of Concussion, Balance Error Scoring System

Key Points

- Assessment of posttraumatic performance in concussion-management programs should be informed by appreciation that premorbid differences related to sport and team membership may exist.
- Caution should be taken in relying on only 1 or 2 measures because these may be compromised by predictable sport and team differences and demographic factors.
- Scores on a baseline measure of postural stability (Balance Error Scoring System) and on the computerized Concussion Resolution Index differed by sport, team, and in some cases sex.
- Differences on the Balance Error Scoring System were correlated with height: taller athletes tended to perform worse than shorter athletes.

In 1989, Barth et al[1] laid the groundwork for using a baseline testing strategy to evaluate the neurocognitive effects of sport-related concussion and to assist in the return-to-participation decision. Since then, baseline assessment has been termed essential[2] and the criterion standard for concussion-management programs.[3] Baseline testing followed by serial neuropsychological evaluations until the athlete's performance has returned to baseline or better represents a formal standard of best practice espoused by many professional associations and multiprofessional panels, including the American Academy of Pediatrics,[4] National Academy of Neuropsychology,[5] and National Athletic Trainers' Association.[6] The alternative approach to assessing an athlete's posttraumatic performance requires comparison with a normative sample. Although this approach has been a backbone in neuropsychology for decades, it does not account for potential premorbid differences in neuropsychological functioning. Given that concussion may reflect subtle changes across several domains of functioning, the normative approach may not be as revealing of such change as the baseline approach, in which within-subjects variance is minimized. Although baseline testing can eliminate such error, an injured athlete may not have undergone a baseline assessment. Comparative norms must then be used to interpret posttraumatic performance. Broglio et al[7] suggested that clinical determinations with the Balance Error Scoring System (BESS) are best informed using comparisons with both baseline administration and normative data.

Given that most structured concussion-management programs include a proactive, baseline testing approach for documenting normal levels of individual performance,[8] only a few systematic investigations of group differences in baseline performance on the selected instruments have been reported. Women generally perform better than men on tasks of verbal memory, verbal fluency, visual attention, and processing speed (PS).[9,10]

Very little work has been done to determine additional group differences on common assessments used to evaluate sport-related concussion. Brown et al[11] reported that simple reaction time (SRT), as measured by the subtests of the Automated Neuropsychological Assessment Metrics, was slower for participants in wrestling, cheerleading, and men's lacrosse than for those in women's soccer and football. These researchers also found that on a memory task, participants from the field hockey team performed better than those from the football team.

In addition to this examination of between-groups differences in cognitive baseline testing, Bressel et al[12] found that basketball players performed systematically worse than gymnasts and soccer players on both static and dynamic measures of balance, including the BESS. Their study was aimed at understanding how balance training for athletes might have to be adjusted depending on sport because different sports might attract athletes with different physical attributes and train different physical skills. However, given that balance is one marker used in baseline testing for later concussion diagnosis, understanding that sports may differ in this regard provides critical information when interpreting both baseline and posttraumatic balance performance.

Therefore, the purpose of our study was to assess sport and team differences in baseline performance on measures of concussion, including the BESS, the Standardized Assessment of Concussion (SAC; Form A), and the Concussion Resolution Index (CRI), and to assess the effect of athlete characteristics height and sex on testing. Reliable and systematic differences in group performance would add further evidence to the importance of baseline and posttraumatic comparison in determining return to participation. Ultimately, the recommendation that an athlete is ready to resume athletic activity is made when posttraumtic symptoms resolve and the athlete recaptures his or her premorbid neurocognitive functioning.[13]

Moreover, unique differences on baseline performance that correlate with sport or team may indicate the need for further research regarding more individualized postconcussion treatment and rehabilitation. Whereas most athletic activities emphasize common cognitive capacities, including reaction time, decision-making speed and efficiency, memory, visual-spatial ability, and postural control, different sports may demand more specific skill sets (eg, baseball versus basketball). Further analysis of the potential team and group differences may support the need for supplementary research to identify additional specialized treatment of concussion depending on the athlete's sport of choice.

METHODS

Participants

The entire census of 437 student-athletes (males = 273, females = 164; age = 19.61 ± 1.64 years [range, 17–27 years], height = 69.89 ± 4.04 inches [177.52 ± 10.26 cm]) enrolled at a National Collegiate Athletic Association Division II university participated in the study. Ten varsity sports and 18 teams were represented: basketball, baseball/softball, cross-country, golf, rowing, soccer, tennis, volleyball (women only), lacrosse (men only), and football (men only), that comprised 18 different teams. Each student-athlete completed mandatory concussion education and baseline testing. Participants and the parents of participants who were minors provided written informed consent. All procedures were approved by the Institutional Review Board of the Florida Institute of Technology. Given that the purpose of the study was to illuminate potential baseline differences that might affect the posttraumatic evaluations conducted in a concussion-management program, no prebaseline exclusionary criteria were used.

Measures and Instruments

We used the BESS,[14] the SAC,[15] and the computerized CRI.[16]

Balance Error Scoring System. The BESS consists of six 20-second trials in which the participant stands in 1 of 3 different positions: feet together, on the nondominant foot, and with the dominant foot directly in front of the nondominant foot (tandem). Participants self-report foot dominance. Each position is performed with the eyes closed and hands on hips when standing on a solid surface, and then is repeated on a foam pad. *Errors* are defined as "moving the hands off of the iliac crests (hips); opening the eyes; step, stumble, or fall; abduction or flexion of the hip beyond 30°; lifting the forefoot or heel off of the testing surface; and remaining out of the proper testing position for greater than five seconds."[14] The total score for the BESS represents the sum of errors made while balancing on the hard surface and foam pad. The total number of errors possible was 10 per pose on each surface, for a total of 60 possible errors for the entire instrument. As noted by Guskiewicz,[14] "trials are considered to be incomplete if the athlete is unable to sustain the stance position for longer than 5 seconds during the entire 20-second testing period. These trials are assigned a standard maximum error score of '10.'" In our study, the 5-second criterion was enforced strictly and may have resulted in somewhat higher total scores than reported in other studies.[17,18]

The total time for administration of the BESS was approximately 5 minutes. Whereas no truly normative studies on BESS performance have been published, researchers studying small samples have shown total mean scores for normal, young participants that vary from 8.4[17] to 12.73.[18] Most researchers have not differentiated scores derived from the 3 stances on the hard versus foam surfaces. Riemann and Guskiewicz[17] reported mean errors of 2.3 on the hard surface and 6.3 on the foam. In their examination of the reliability of a modified scoring system for the BESS (eliminating the 2-footed stance), Hunt et al[19] showed with a small sample of high school athletes that the single-legged stance controlled the bulk of the variance in

Table 1. Concussion Resolution Index Subtests and Index Loadings

Index	Description
Processing speed	
Animal decoding	Participants are instructed to type number keys that correspond with animals.
Symbol scanning	Participants must determine whether a specific symbol is present among distractor symbols.
Simple reaction time	
Reaction time	Participants must press the space bar when a target shape is presented.
Cued reaction time	Participants must press the space bar when a target shape is presented immediately after a cue.
Complex reaction time	
Visual recognition 1	A series of pictures is presented, and the participant is instructed to press the space bar when a picture is recognized as being previously presented during the task.
Visual recognition 2	The pictures from the visual recognition 1 sequence are repeated after a delay, and participants are instructed to press the space bar if they recognize the picture from the earlier trials.

scores. The foam-pad error score was greater by a factor of 2 than that on the firm surface.

Standardized Assessment of Concussion. The SAC is a sideline measurement of concussion that generally is conducted immediately when a head injury is suspected.[20] Four domains associated with mental status and neurocognitive ability are measured by the SAC: orientation, immediate memory (5-item word list), concentration (digits backward, months of the year backward), and delayed recall (previous word list). They produce a total possible score of 30.[21] Barr and McCrea[21] suggested that deviations of 1 point from baseline are clinically important. The version that we used for baseline assessment also included a section on exertional maneuvers that mimic the conditions under which the SAC is normally administered.[15] These maneuvers included the participant's completing 5 repetitions of each of the following exercises: jumping jacks, sit-ups, push-ups, and knee bends. Total administration time was approximately 10 minutes, and the participant's total score was noted on the record form. Published norms for the SAC are a total score of 26.6 $\pm$ 2.2 and domain scores of 4.8 $\pm$ 0.43 for orientation, 14.51 $\pm$ 0.98 for immediate memory, 3.40 $\pm$ 1.3 for concentration, and 3.84 $\pm$ 1.1 for delayed memory.[20]

Concussion Resolution Index. The CRI is a computerized neuropsychological screening instrument that "was developed specifically to compare an athlete's postconcussion performance with his or her own pretrauma baseline performance."[16] Administration time for the CRI averages 25 minutes.[22] Before the neurocognitive tests, participants are instructed to provide demographic data, including ethnicity, age, and sport in which they participate, and minimal background medical information. The CRI uses 6 subtests to measure memory, reaction time, and speed of both decision making and information processing, and these subtests are used to create 3 indices: PS, complex reaction time (CRT), and SRT.[16] Measures of response speed are included in all 3 indices, whereas only the CRT and SRT indices also include a measure of the number of errors the participant made during the subtest. A brief description of the CRI individual subtests and the derived indices to which they contribute is provided in Table 1. More complete descriptions of the CRI and its subtests are presented elsewhere.[23]

Procedure

The neurocognitive and balance measures were administered after we obtained informed consent . All participants completed the 3 instruments within a single test session that lasted for less than 1 hour. The CRI was administered in a small-group setting (typically 8–12 participants) in a computer laboratory, whereas the SAC and BESS were administered individually in separate rooms. Order of administration was as follows: CRI, BESS, and SAC. In the rare instances that the CRI scores were autoinvalidated, the participants repeated the CRI and obtained a valid outcome. Data from invalid administrations were not included in the analysis.

Data Analysis

All analyses that compared or related performance by sport combined the female and male athletes who participated in that sport. The rationale for this grouping was that if particular sports demanded or developed certain abilities or attracted participants with common physical attributes, then not including sex in the analysis was appropriate. Given that volleyball was limited to females and lacrosse and football were limited to males, no unbiased sex grouping could be formed, and those activities were not included in the sport analysis, resulting in 7 sports for comparison under this condition ($n = 355$). For the team analysis, the entire sample of athletes was included ($N = 437$). The analyses by team represented the usual ecology of sport teams in that sex and sport are confounded. The distribution of participants by these sport and team categorizations is shown in Table 2. In comparative analyses using analysis of variance (ANOVA) or multivariate ANOVA (MANOVA), normality of distribution as determined by the Wilk-Shapiro test and homogeneity of variance as determined by the Levene statistic were ensured first. Unless stated otherwise for specific comparisons, these were not different. Effect sizes are presented as η_p^2 as produced in SPSS (version 19; IBM Corporation, Armonk, NY) and interpreted according to Cohen as small ($\leq$0.01), medium (0.02–0.06), and large ($\geq$0.14).[23] In the MANOVAs, we used the Wilks Λ as the multivariate statistic except for sex comparisons, for which we used the Hotelling *T* statistic because only 2 groups were involved. We used the conservative Hochberg GT 2 for post hoc analysis of differences found with ANOVA because it controls for family-wise error and also takes unequal group sizes into account. To determine the influence of demographic factors on the sport and team differences, additional post hoc analyses were conducted to assess any moderating role of sex and height. We used the 2-factor (sex, sport) MANOVA and the analysis of covariance (ANCOVA) and multivariate ANCOVA (MANCOVA) with the covariate of

Table 2. Participant Groupings by Sport and Team

Sport	Team	No.
Baseball/softball (n = 70)	Baseball	48
	Softball	22
Basketball (n = 47)	Men	24
	Women	23
Cross-country (n = 36)	Men	25
	Women	11
Golf (n = 24)	Men	14
	Women	10
Rowing (n = 60)	Men	32
	Women	28
Soccer (n = 73)	Men	37
	Women	36
Tennis (n = 38)	Men	27
	Women	11
Not applicable	Football[a]	41
	Lacrosse[a]	21
	Volleyball[b]	18

[a] Indicates the team was limited to male participants.
[b] Indicates the team was limited to female participants.

height. We reanalyzed the total BESS score comparisons across sports and teams using ANCOVA with height as a covariate. We also conducted a similar comparison of the hard-surface and foam-pad scores using MANCOVA with height as a covariate. The α level was set a priori at .05. SPSS was used for all analyses.

RESULTS

Balance Error Scoring System

Total BESS scores differed across sports ($F_{6,347} = 3.147$, $P = .005$), with a medium effect size ($\eta_p^2 = 0.05$). Post hoc Hochberg GT 2 comparisons revealed that soccer athletes performed better than basketball players (Table 3; Figure 1). When the sports were regrouped into male and female teams, total BESS scores differed ($F_{16,419} = 2.71$, $P < .001$) and produced a medium effect size ($\eta_p^2 = 0.09$). Post hoc comparisons indicated that the men's soccer team performed better than the men's basketball team, whereas the women's soccer team performed better than the men's basketball, lacrosse, and football teams (Table 4; Figure 2).

Differences in the hard-surface and foam-pad subscales were assessed via separate MANOVAs for sport and team. We found a difference among sports ($\Lambda = 0.93$, $F_{12,692} = 2.106$, $P = .02$, $\eta_p^2 = 0.015$), with the univariate comparisons revealing a difference only for the hard-surface portion of the BESS ($F_{6,347} = 3.33$, $P = .003$, $\eta_p^2 = 0.05$). Post hoc inspection of the means indicated that soccer players performed better than basketball and baseball/softball players; no other differences were noted (Table 3). Clearly, the differences in the total BESS scores were due to variance in the hard-surface component. A difference also was found among teams as indicated by the MANOVA ($\Lambda = 0.87$, $F_{32,836} = 1.875$, $P = .003$, $\eta_p^2 = 0.07$). In the univariate analysis, teams differed in both the hard-surface component ($F_{16,419} = 2.302$, $P = .003$, $\eta_p^2 = 0.81$) and the foam-pad component ($F_{16,419} = 2.017$, $P = .01$, $\eta_p^2 = 0.07$). Post hoc Hochberg GT 2 comparisons showed that men's basketball and football teams performed worse than the men's and women's soccer teams. No other differences were observed (Table 4).

Table 3. Balance Error Scoring System (BESS) Total Score by Sport (Mean ± SD)

Sport	No.	Total
Baseball/softball	70	19.21 ± 6.909
Basketball	47	22.02 ± 7.728
Cross country	36	19.78 ± 6.986
Golf	25	19.28 ± 7.397
Rowing	59	20.17 ± 7.240
Soccer	74	16.43 ± 7.141[a]
Tennis	38	20.82 ± 7.880

[a] Indicates difference between soccer and basketball (*P* = .002).

Standardized Assessment of Concussion

Total SAC scores did not differ across sports or teams (Tables 5 and 6, respectively). Comparison of the domains of the SAC via MANOVA indicated no differences among sports ($\Lambda = 0.913$, $F_{36,1553} = 1.063$, $P = .37$, $\eta_p^2 = 0.023$).

Concussion Resolution Index

Performance on the CRI indices differed across sports ($\Lambda = 0.90$, $F_{18,979} = 2.179$, $P = .003$, $\eta_p^2 = 0.04$). Univariate analyses revealed differences for the SRT ($F_{6,348} = 4.940$, $P < .001$, $\eta_p^2 = 0.08$) but not for the CRT ($F_{6,348} = 1.395$, $P = .23$, $\eta_p^2 = 0.024$) or PS ($F_{6,348} = 1.2534$, $P = .28$, $\eta_p^2 = 0.021$). Post hoc Hochberg tests for SRT revealed that basketball players exhibited longer SRTs than soccer ($P < .001$) and baseball/softball players ($P = .03$). Furthermore, soccer players performed better on tasks of SRT than golfers ($P < .009$). In comparing measures of variance for the 3 indices, it was apparent that much greater variability existed in the CRT and PS measures than in SRT (Table 7; Figure 3). Soccer and baseball/softball appeared to have distributions that were different from golf and basketball for SRT and CRT but not from the other sports. Processing speeds were consistent across all sports.

Similar to the sport comparisons, the CRI indices differed across teams ($\Lambda = .79$, $F_{48,1244} = 2.17$, $P < .001$, $\eta_p^2 = 0.08$). Univariate analyses revealed differences across teams for the SRT ($F_{16,420} = 2.489$, $P = .001$, $\eta_p^2 = 0.09$) and PS ($F_{16,420} = 2.28$, $P = .003$, $\eta_p^2 = 0.08$) but not for the CRT ($F_{16,420} = 1.557$, $P = .08$, $\eta_p^2 = 0.056$). Post hoc results by team tracked similarly to the sport analysis, such that the 2 soccer teams and the baseball team performed better than the men's basketball team in the SRT. Regarding the PS, softball ($P = .03$) and women's rowing ($P = .03$) outperformed the men's cross-country team (Table 8).

A further parsing of the CRI into the 6 individual subtests that feed into the 3 indices did not reveal any systematic outcomes that differed from the index analyses ($P > .05$).

Demographic Factors

Given that balance measures may be influenced by morphologic characteristics, height appeared to be the most salient organismic contributor.

Sex. A 2-factor MANOVA with sex and sport as the factors showed that women performed better than men on the CRI (Hotelling $T = 0.082$, $F_{3,336} = 9.166$, $P < .001$, $\eta_p^2 = 0.076$), evidencing faster CRTs ($F_{1,338} = 14.005$, $P < .001$, $\eta_p^2 = 0.040$) and PSs ($F_{1,338} = 17.784$, $P < .001$, $\eta_p^2 = 0.050$). Simple reaction times were identical for men and

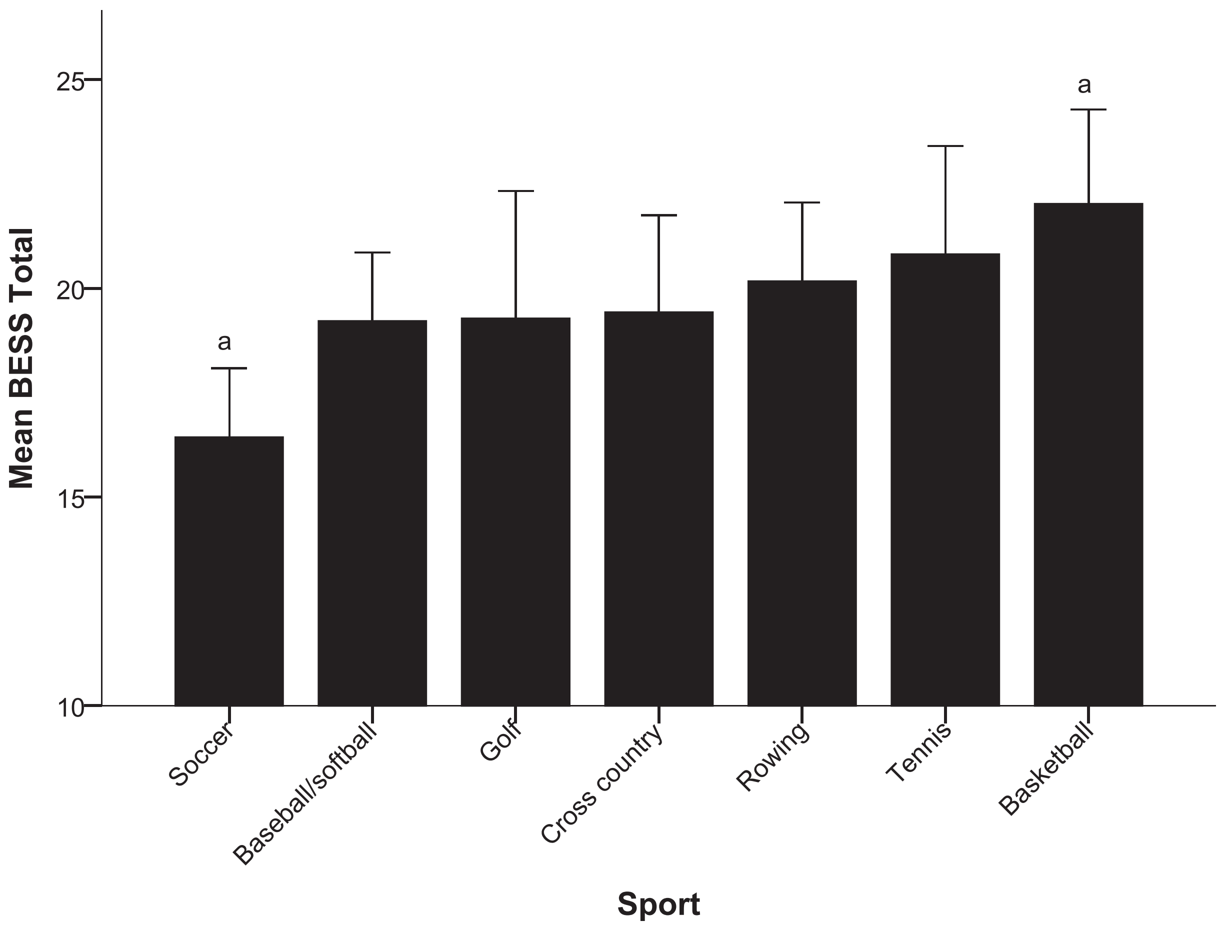

Figure 1. Mean total Balance Error Scoring System (BESS) scores by sport. The error bars represent 95% confidence intervals for the group means. Note the large relative differences between basketball and soccer and the overlap among the other sports. [a]Indicates soccer athletes performed better than basketball athletes.

Table 4. Balance Error Scoring System (BESS) Total Score by Team (Mean ± SD)

Team	No.	Total
Baseball	48	19.88 ± 6.153
Football[d]	41	22.22 ± 8.162
Lacrosse[d]	21	22.52 ± 5.947
Men's basketball	24	25.04 ± 7.771
Men's cross country	25	20.32 ± 6.762
Men's golf	14	19.14 ± 6.011
Men's rowing	32	21.03 ± 7.032
Men's soccer	37	17.51 ± 8.082[b]
Men's tennis	27	20.22 ± 7.663
Softball	22	17.77 ± 8.303
Volleyball[c]	18	19.39 ± 7.212
Women's basketball	23	18.87 ± 6.434
Women's cross country	11	18.55 ± 7.660
Women's golf	10	20.00 ± 9.487
Women's rowing	28	18.96 ± 7.406
Women's soccer	37	15.35 ± 5.973[a]
Women's tennis	11	22.27 ± 8.592

[a] Indicates women's soccer was different from mens' basketball ($P < .001$), lacrosse ($P = .045$), and football ($P = .003$).
[b] Indicates men's soccer was different from men's basketball ($P = .02$).
[c] Indicates the team was limited to female participants.
[d] Indicates the team was limited to male participants.

women. As introduced previously, only SRT differed across sports. The interaction of sex and sport on CRI indices was not different in any test ($P > .05$).

Height. Participant height was correlated with the hard surface ($r_{401} = 0.165$, $P = .001$), foam pad ($r_{401} = 0.229$, $P < .001$), and total BESS scores ($r_{401} = 0.243$, $P < .001$) (Tables 9 and 10 for sport and team, respectively). A reanalysis of total BESS score comparisons across sports and teams with height inserted into the ANCOVA model revealed that height was a covariate for sport ($F_{1,326} = 11.212$, $P = .001$, $\eta_p^2 = 0.033$) and team ($F_{1,385} = 5.109$, $P = .02$, $\eta_p^2 = 0.013$) analyses, eliminating the differences found in the initial analyses. A similar comparison via MANCOVA of hard-surface and foam-pad scores with height included as a covariate also eliminated the multivariate team ($\Lambda = 0.906$, $F_{32,768} = 1.217$, $P = .19$, $\eta_p^2 = 0.048$) and sport ($\Lambda = 0.942$, $F_{12,650} = 1.650$, $P = .07$, $\eta_p^2 = 0.030$) differences. Clearly, height was a moderating factor controlling BESS performance.

DISCUSSION

Scores on a baseline measure of postural stability (BESS) and on the computerized CRI differed by sport, by team, and in some cases by sex; however, similar to previous studies, consistent overall findings between sexes were not found.[24] These results indicated a stronger performance in

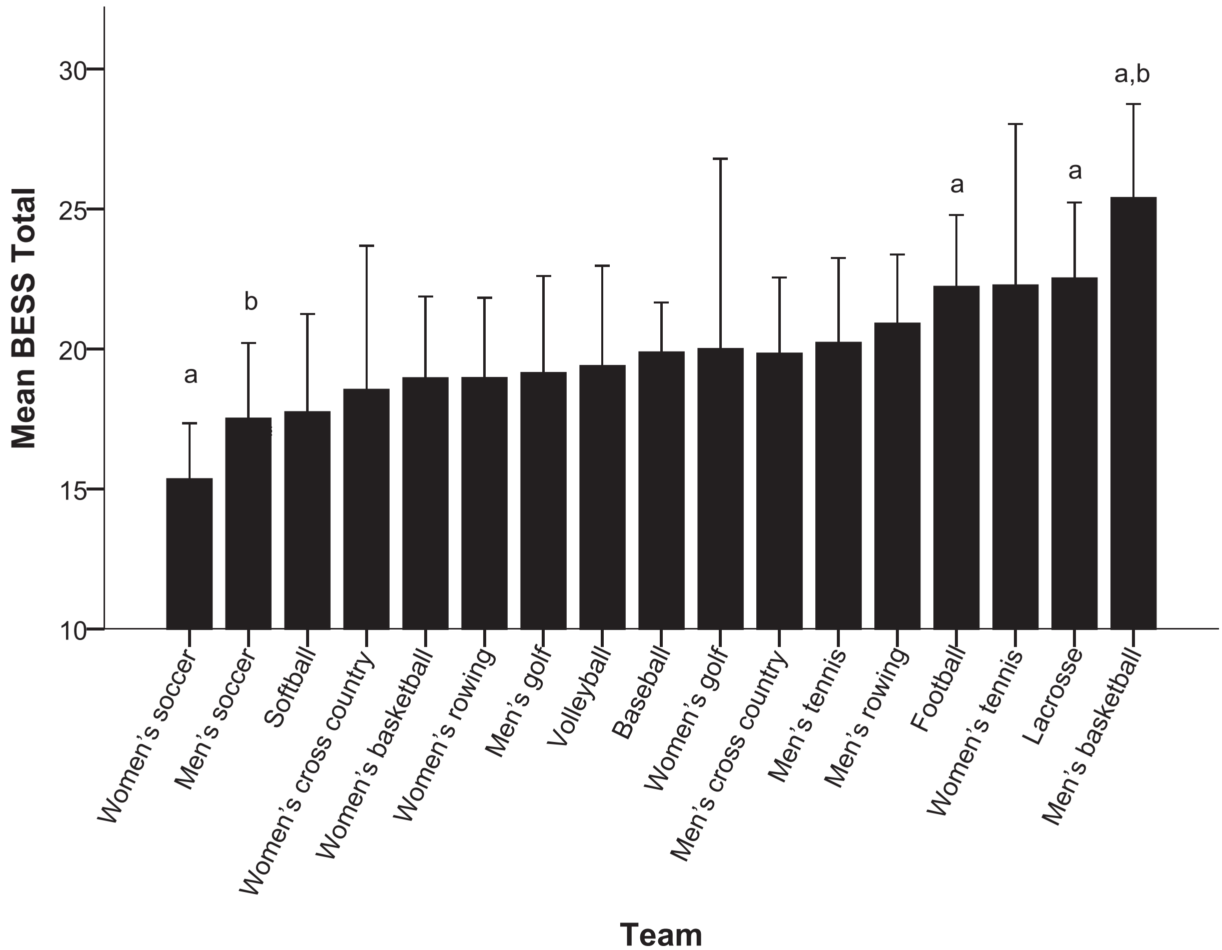

Figure 2. Total Balance Error Scoring System (BESS) scores by team. The error bars represent 95% confidence intervals for the group means. Note the large relative differences between basketball and soccer and the overlap among the other sports. [a]Indicates women's soccer performed better than men's basketball, lacrosse, and football. [b]Indicates men's soccer performed better than men's basketball.

soccer than in other sports and a weaker performance in basketball, particularly the men's team, than in other sports and teams.

Within the BESS results, soccer, particularly the women's team, performed the best, and basketball, particularly the men's team, performed the worst performance. Differences among athletic teams were found when measured on the hard surface but not when measured on the foam pad, where within-group variance was very high. Differences on the BESS also were correlated with height, indicating that taller athletes tended to perform worse than shorter athletes. Furthermore, given that basketball had taller participants than most other sports and had the weakest balance performance of the sports measured, we intimate that height was an overall contributory factor to the basketball players' poor performance on baseline balance measures. This conclusion was supported by the ANCOVAs in which the sport and team differences

Table 5. Standardized Assessment of Concussion Total Score by Sport (Mean ± SD)

Sport	No.	Total
Baseball/softball	70	27.46 ± 1.639
Basketball	47	27.11 ± 1.902
Cross- country	36	27.11 ± 1.769
Golf	25	27.32 ± 2.036
Rowing	59	27.42 ± 1.621
Soccer	73	27.18 ± 2.546
Tennis	38	27.45 ± 1.870

Table 6. Standardized Assessment of Concussion Total Score by Team (Mean ± SD)

Team	No.	Total
Baseball	48	27.42 ± 1.596
Football[b]	41	27.22 ± 1.864
Lacrosse[b]	21	27.00 ± 2.049
Men's basketball	24	26.71 ± 1.899
Men's cross-country	25	26.68 ± 1.865
Men's golf	14	27.14 ± 2.143
Men's rowing	32	27.38 ± 1.661
Men's soccer	37	26.97 ± 2.555
Men's tennis	27	27.48 ± 1.740
Softball	22	27.55 ± 1.765
Volleyball[a]	18	27.11 ± 2.026
Women's basketball	23	27.52 ± 1.855
Women's cross-country	11	28.09 ± 1.044
Women's golf	10	27.90 ± 1.663
Women's rowing	28	27.36 ± 1.704
Women's soccer	36	27.39 ± 2.555
Women's tennis	11	27.36 ± 2.248

[a] Indicates the team was limited to female participants.
[b] Indicates the team was limited to male participants.

Table 7. Concussion Resolution Index Score by Sport (Mean ± SD)

Sport	No.	Simple Reaction Time	Complex Reaction Time	Processing Speed
Baseball/softball	71	0.384 ± 0.051	0.713 ± 0.109	2.684 ± 0.458
Basketball	45	0.420 ± 0.065[b]	0.743 ± 0.103	2.738 ± 0.420
Cross-country	36	0.401 ± 0.070	0.726 ± 0.082	2.901 ± 0.740
Golf	25	0.416 ± 0.057	0.755 ± 0.112	2.794 ± 0.290
Rowing	58	0.389 ± 0.064	0.699 ± 0.099	2.666 ± 0.424
Soccer	76	0.368 ± 0.047[a]	0.708 ± 0.131	2.664 ± 0.408
Tennis	39	0.392 ± 0.069	0.716 ± 0.126	2.619 ± 0.371

[a] Indicates soccer was different from golf ($P = .009$).
[b] Indicates basketball was different from soccer ($P < .001$) and baseball/softball ($P = .03$).

disappeared when height was used as a covariate. These systematic differences in BESS performance attributable to sport, team, and height reinforced the notion that baseline differences can complicate posttraumatic data interpretation. This finding appeared to be novel for this population, as researchers have investigated postural stability and height primarily in a geriatric population. Further study in athletic team differences could identify whether these differences may be characteristics of the athletes these sports recruit or may have resulted from the sample we studied. These results should serve as a caution for using assessments that rely primarily on hard-surface balance stances, such as the Sport Concussion Assessment Tool 2 (SCAT-2).[25] Systematic group and demographic differences could add ambiguity to judgments based on deviations from a group norm.

A between-teams difference in the BESS similarly has been shown in a previous study.[15] These differences in baseline measures due to sport support the need for caution in using generic normative values for assessing later effects of head trauma. Our study indicated that premorbid postural stability differences exist among sports, with height as a key moderating factor. Given that preinjury baseline assessments are not always available, the best method for posttraumatic comparison is to rely on age, sex, and sport-specific normative values.

The CRI results showed generally better performance by baseball/softball and soccer players than by golfers and

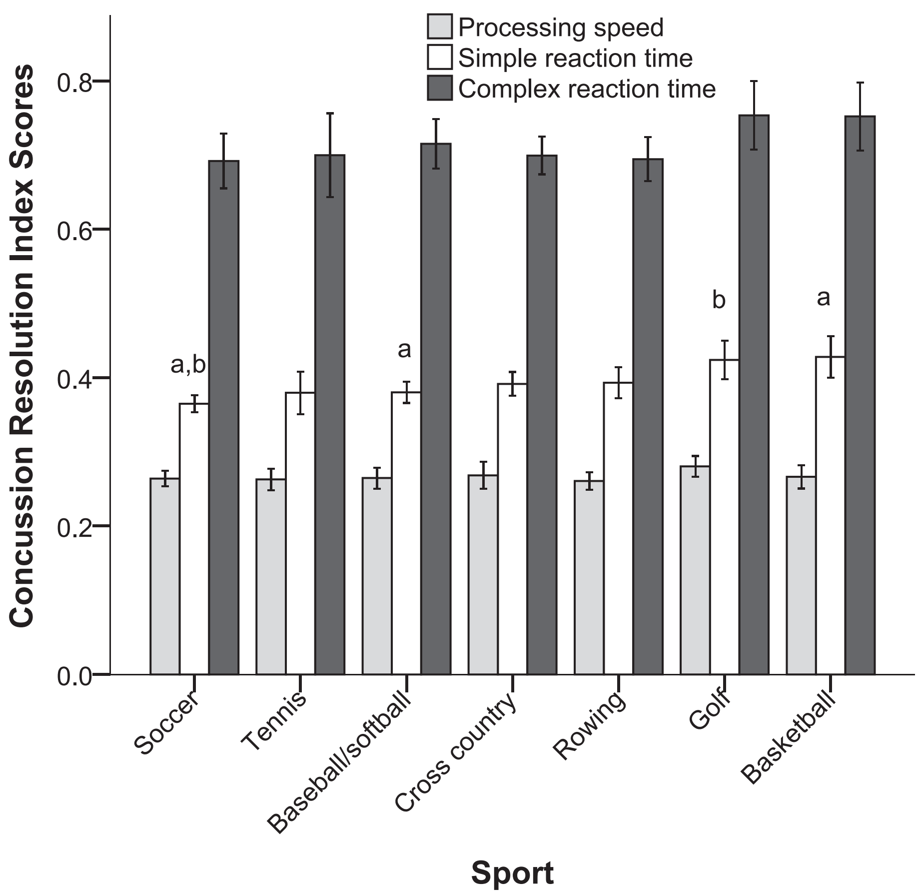

Figure 3. Concussion Resolution Index scores by sport. The error bars represent 95% confidence intervals for the group means. The processing speed index means were reduced by 1 decimal point so they would fit on the graph with the reaction time measures. Note the large relative differences between basketball and soccer and the overlap among the other sports. [a]Indicates soccer and baseball/softball athletes exhibited shorter simple reaction times than basketball athletes. [b]Indicates soccer athletes exhibited shorter simple reaction times than golf athletes.

Table 8. Concussion Resolution Index Score by Team (Mean ± SD)

Team	No.	Simple Reaction Time	Complex Reaction Time	Processing Speed
Baseball	48	0.379 ± 0.046	0.729 ± 0.113	2.750 ± 0.476
Football[d]	41	0.385 ± 0.050	0.725 ± 0.107	2.747 ± 0.402
Lacrosse[d]	23	0.386 ± 0.074	0.726 ± 0.131	2.894 ± 0.515
Men's basketball	24	0.434 ± 0.061	0.760 ± 0.111	2.815 ± 0.383[c]
Men's cross country	25	0.402 ± 0.080[a]	0.732 ± 0.085	3.108 ± 0.780
Men's golf	14	0.421 ± 0.066	0.799 ± 0.119	2.875 ± 0.347
Men's rowing	32	0.386 ± 0.058	0.714 ± 0.113	2.741 ± 0.479
Men's soccer	39	0.360 ± 0.044	0.720 ± 0.161	2.270 ± 0.434
Men's tennis	28	0.399 ± 0.076	0.737 ± 0.139	2.675 ± 0.369
Softball	23	0.397 ± 0.060	0.679 ± 0.091	2.543 ± 0.391
Volleyball[b]	18	0.408 ± 0.058	0.715 ± 0.096	2.640 ± 0.383
Women's basketball	21	0.404 ± 0.068	0.724 ± 0.092	2.648 ± 0.415
Women's cross country	11	0.401 ± 0.042	0.711 ± 0.077	2.457 ± 0.365
Women's golf	10	0.414 ± 0.047	0.710 ± 0.072	2.693 ± 0.162
Women's rowing	30	0.390 ± 0.068	0.671 ± 0.075	2.572 ± 0.309
Women's soccer	37	0.375 ± 0.050	0.694 ± 0.089	2.658 ± 0.386
Women's tennis	11	0.372 ± 0.041	0.662 ± 0.059	2.479 ± 0.356

[a] Indicates men's cross country was different from softball ($P = .03$) and women's rowing ($P = .03$).
[b] Indicates the team was limited to female participants.
[c] Indicates men's basketball was different from men's and women's soccer ($P < .001$ and $P = .02$, respectively) and baseball ($P = .03$).
[d] Indicates the team was limited to male participants.

basketball players. Finding apparently robust differences in reaction times and PSs across sports, especially basketball, was surprising because these abilities are clearly important for effective participation. However, such differences in baseline performance among sports and teams lend credence to more individualized assessments for posttraumatic return-to-participation decisions.

Barr and McCrea[21] suggested that even a 1-point decline in the total SAC score is sufficient to warrant caution in allowing an athlete to continue participating in practice or competition without a more detailed assessment. The finding of no sport, team, or sex differences in the SAC supports the current use of this measure as a sideline assessment that is fairly robust to non–trauma-related sport factors.

Researchers have indicated the importance of baseline measures to obtain an accurate assessment of the presence of concussion.[26] Premorbid differences may prevent baseline data from being adequately comparable among athletes when trauma occurs. Differences between sexes may not be found uniformly across baseline measures, but when found postconcussion, they are important.[27]

Our study extends the knowledge of how to find differences among sports on baseline measures. We further expanded on differences found in the BESS in previous studies[14] and added baseline-measure differences in both the SAC and CRI. The limitations of our study include possible variability due to motivational factors and history of concussion or mental health conditions. Given the lack of effort testing in conjunction with this baseline testing, we were not certain the sport and team differences we found were due to group differences unrelated to effort. However, we found no credible indicators that whole teams would have been affected in a systematic fashion. The actual test sessions included individuals from different sports and teams, so team dynamics were less likely. An additional factor, intellectual ability, potentially could have a mediating effect on performance for the neurocognitive measures. Future research on academic factors, such as intelligence, grade point average, or SAT (The College Board, New York, NY) scores, may lend further credence to the effect of premorbid intellectual levels on baseline measurement.

Table 9. Height by Sport (Mean ± SD)

Sport	No.	Total, in (cm)
Basketball	47	73.19 ± 5.09 (185.90 ± 12.93)
Baseball/softball	71	69.80 ± 3.88 (177.29 ± 9.86)
Cross country	34	68.29 ± 3.37 (173.46 ± 8.56)
Golf	25	69.36 ± 3.89 (176.17 ± 9.88)
Rowing	47	69.87 ± 4.32 (177.47 ± 10.97)
Soccer	75	68.40 ± 3.74 (173.74 ± 9.5)
Tennis	38	69.00 ± 3.21 (175.26 ± 8.15)

CONCLUSIONS

Assessment of posttraumatic performance in concussion-management programs should be informed by appreciation

Table 10. Height by Team (Mean ± SD)

Team	No.	Total, in (cm)
Baseball	48	71.98 ± 2.45 (182.83 ± 6.22)
Football[a]	33	71.85 ± 2.92 (182.5 ± 7.42)
Lacrosse[a]	19	71.37 ± 3.10 (181.28 ± 7.87)
Men's basketball	23	77.17 ± 3.28 (196.01 ± 8.33)
Men's cross-country	23	70.00 ± 2.45 (177.8 ± 6.22)
Men's golf	14	71.64 ± 2.62 (181.97 ± 6.65)
Men's rowing	27	72.81 ± 3.03 (184.94 ± 7.7)
Men's soccer	38	71.11 ± 2.59 (180.62 ± 6.58)
Men's tennis	27	70.11 ± 2.62 (178.08 ± 6.65)
Softball	24	65.42 ± 1.93 (166.17 ± 4.90)
Volleyball[b]	18	69.39 ± 1.54 (176.25 ± 3.91)
Women's basketball	22	69.14 ± 3.14 (175.62 ± 7.98)
Women's cross-country	11	64.73 ± 1.90 (164.41 ± 4.83)
Women's golf	10	66.50 ± 3.47 (168.91 ± 8.81)
Women's rowing	22	66.32 ± 2.66 (168.45 ± 6.76)
Women's soccer	37	65.62 ± 2.49 (166.67 ± 6.32)
Women's tennis	11	66.27 ± 2.97 (168.33 ± 7.54)

[a] Indicates the team was limited to male participants.
[b] Indicates the team was limited to female participants.

that premorbid differences that relate to sport and team membership may exist. Posttraumatic performance may vary because of these factors. Given that comparison with group norms is necessary in the absence of baseline measurement, our results support caution in relying on only 1 or 2 measures because these may be compromised by predictable sport or team differences and demographic factors.

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