

Postural Stability in Healthy Child and Youth Athletes: The Effect of Age, Sex, and Concussion-Related Factors on Performance

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Background: Postural stability plays a key role in sport performance, especially after concussion. Specific to healthy child and youth athletes, little is known about the influence development and sex may have on postural stability while considering other subjective clinical measures used in baseline/preinjury concussion assessment. This study aims to describe age- and sex-based trends in postural stability in uninjured child and youth athletes at baseline while accounting for concussion-related factors.

Hypotheses: (1) Postural stability performance will improve with age, (2) females will display better postural stability compared to males, and (3) concussion-like symptoms will affect postural stability performance in healthy children and youth.

Study Design: Cross-sectional study.

Level of Evidence: Level 3.

Methods: This study comprised 889 healthy/uninjured child and youth athletes (54% female, 46% male) between the ages of 9 and 18 years old. Participants completed preseason baseline testing, which included demographic information (age, sex, concussion history), self-report of concussion-like symptoms (Post-Concussion Symptom Inventory [PCSI]–Child and PCSI–Youth), and measures of postural stability (BioSway; Biodex Medical Systems). Two versions of the PCSI were used (PCSI-C, 9- to 12-year-olds; PCSI-Y, 13- to 18-year-olds). Postural stability was assessed via sway index under 4 sway conditions of increasing difficulty by removing visual and proprioceptive cues.

Results: In children aged 9 to 12 years old, there were significant age- ($P < 0.05$) and sex-based effects ($P < 0.05$) on postural stability. Performance improved with age, and girls performed better than boys. For youth ages 13 to 18 years old, postural stability also improved with age ($P < 0.05$). In both child and youth subgroups, postural stability worsened with increasing concussion-like symptoms ($P < 0.05$).

Conclusion: There are developmental and baseline symptom trends regarding postural stability performance.

Clinical Relevance: These findings provide a preliminary foundation for postconcussion comparisons and highlight the need for a multimodal approach in assessing and understanding physical measures such as postural stability.

Keywords: postural stability; youth; athletes; concussion; symptom

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Multimodal preinjury/baseline testing that includes subjective and objective measures as a benchmark for postinjury comparisons is popular in the sports community and has been suggested internationally to be helpful in providing additional information during concussion management and return-to-activity decision-making.^{20,25} However, there are 2 current limitations to baseline testing: (1) it has relied heavily on subjective reports of concussion symptoms²⁵ and computerized neurocognitive assessment⁶ and (2) preinjury values derived from baseline studies have focused on adult and collegiate populations.^{17,18} A recent study indicated that preinjury factors such as age, sex, and baseline symptoms affect postinjury performance on cognitive tasks and suggest further study in other assessment domains.⁷ In the absence of baseline testing, making pre- and postinjury comparisons is challenging, and an understanding of the variety of factors that play a role in postural stability can assist clinicians in identifying physical impairments postconcussion.

Factors such as age affect postural stability.^{2,4} Postural stability performance improves from childhood (ages 8-10 years)⁴ to adulthood (ages 21-30 years).² A recent systematic review indicated that postural stability is not fully developed on average by pubertal onset (ages 8-14 years),²⁴ as dynamic perception and utilization of visual cues for postural control continue to mature throughout adolescence.³⁰ Understanding these developmental trends in the context of other measures collected during baseline testing (eg, concussion-like symptoms) has the potential to enhance understanding of changes in performance after injury, especially in an understudied population such as child and youth athletes.

Further, sex-based differences in children regarding postural stability indicate that girls exhibit better postural stability than boys of similar ages.^{8,10,19,21,23,29} Girls aged 7 to 8 years have better use of vestibular information and consequently reduced body sway compared with boys of the same age.²³ Conversely, a cross-sectional study on adolescent athletes showed no differences between males and females on dynamic postural stability tasks.¹⁵ Furthermore, a longitudinal assessment of postural stability performance (Star Excursion Balance Test) in adolescent athletes found that males had better performance over time in the posterior-lateral direction compared with females, who performed better in the anterior direction.¹⁴ These findings suggest a complex relationship between sex and postural stability in healthy children and youth. Understanding how sex-based differences play a role in baseline performance may be crucial to differential concussion management between males and females.

In the realm of multimodal preinjury assessments, transient or situational factors such as physical, cognitive, emotional, and fatigue symptoms play a role in performance.²⁶ Pediatric guidelines for concussion assessment have underlined the clinical importance of monitoring postural stability in parallel to other common clinical measures collected within a baseline assessment (ie, symptom reports) to capture a holistic account of child and youth performance on physical tasks.²² How child

and youth athletes feel in the present moment can provide important contextual information that may assist in the interpretation of postconcussion comparisons of postural stability scores.^{7,17,25} For example, a large sample of healthy/uninjured child and adolescent athletes displayed a wide range of concussion-like symptoms.¹⁷ However, how these baseline symptoms affect baseline postural stability is not known. Furthermore, understanding baseline characteristics for child and youth athletes is important given that organized sports increases the risk of concussion by a factor of nearly 6 times.³ Athletes have unique activity demands that may influence concussion-like symptoms experienced at baseline; these symptoms may or may not be related to postural stability, and this study can enhance our understanding of the relationship between objective and subjective measures used in clinical settings.

The purpose of this study was to examine factors that may influence postural stability in a healthy child and youth athlete population (baseline/preinjury), that is, the influence of age, sex, and baseline concussion-like symptoms on postural stability performance. In line with current literature, the following hypotheses were developed: (1) postural stability in youth athletes will improve with age, (2) female youth athletes will have better postural stability than males, and (3) self-reported concussion-like symptoms at baseline will be associated with decreased postural stability performance.

METHODS

Ethics approval was received from Holland Bloorview Research Ethics Board. All participants and/or their parents provided informed written consent prior to participation.

A cross-sectional study of child and youth athletes was conducted in which baseline data were collected. A convenience sample of 889 child and youth athletes (age range, 9-18 years) was recruited from local community sports organizations. Participants with a diagnosis of developmental delay, with a neurological condition, who were experiencing symptoms from a previous concussion, or those who did not speak English were excluded from the study. While participants were permitted to have a history of concussion, they had to be asymptomatic and be fully participating in school and sport at the time of study entry (Table 1). Participants aged 9 to 12 years completed the child version of the Post-Concussion Symptom Inventory (PCSI-C), and participants aged 13 to 18 years completed the youth version (PCSI-Y).

Measures

Postural Stability

Postural stability was assessed using a modified Clinical Test of Sensory Integration of Balance (mCTSIB) on the BioSway Portable Balance System (Biodex Medical Systems). The BioSway provides more objective ratings of sway in the context of visual and somatosensory information. The mCTSIB has 4 conditions of varying difficulty: condition 1 (eyes open, firm surface [EO/FS]) incorporates visual, vestibular, and

Table 1. Descriptives of all child and youth athletes according to version of the Post-Concussion Symptom Inventory (PCSI)

| | PCSI Version ^a | |
|--|---------------------------|--------------------|
| | PCSI-C (n = 334) | PCSI-Y (n = 555) |
| Age, y, mean ± SD | 11.19 ± 0.86 | 14.26 ± 1.23 |
| Sex, % (n) | | |
| Males | 50.6 (169) | 43.9 (244) |
| Females | 49.4 (165) | 56.1 (312) |
| PCSI total score, mean ± SD (range) | 1.62 ± 2.29 (0-13) | 5.26 ± 6.95 (0-44) |
| Concussion history, % (n) | | |
| No previous concussions | 82.6 (276) | 69.2 (385) |
| Previous concussion(s) | 16.8 (56) | 30.6 (170) |
| No. of previous concussions, % (n) | | |
| 1 | 15.0 (50) | 19.4 (108) |
| 2 | 0.6 (2) | 6.5 (36) |
| 3 | 1.2 (4) | 4.0 (22) |
| 4 | 0 (0) | 0.9 (5) |
| Body mass index, kg/m ² , mean ± SD | 18.37 ± 2.84 | 21.13 ± 3.09 |

^aPCSI-C is the version for children aged 9 to 12 years old; PCSI-Y is the version for youth aged 13 to 18 years old.

somatosensory inputs; condition 2 (eyes closed, firm surface [EC/FS]) eliminates visual input to evaluate vestibular and somatosensory reactions; condition 3 (eyes open, uneven foam surface [EO/US]) evaluates somatosensory interaction with visual input; and condition 4 (eyes closed, uneven foam surface [EC/US]) evaluates somatosensory interaction with vestibular input.¹ For each condition, the BioSway tracks the participant's sway angle and direction from center, creating a stability index (ie, average position from the center). The stability index only provides information on the participant's position from center; thus, the standard deviation of the stability index is used to quantify how much the participant swayed, computing a sway index. The sway index was the main outcome of interest in this study. The *sway index* is defined as the standard deviation of position over the length of the test, interpreted to be the absolute vector length deviation from the mean vector end point.¹ Use of this variable is supported by previous studies that utilized sway index to capture postural stability.^{5,27,28}

Post-Concussion Symptom Inventory

Concussion-like baseline symptoms were collected at 1 time point using the PCSI as part of a baseline assessment protocol. The PCSI is a self-report symptom assessment scale designed for

children and adolescents to assess postconcussion symptoms and has been found to have good validity and reliability among these age groups.²⁶ Two versions of the PCSI were used based on the broad age range of participants in this study. A 22-item version of the PCSI was used for youth aged 13 to 18 years old (PCSI-Y), with a 7-point rating scale from 0 to 6 capturing severity of symptoms (0 = not a problem, 3 = somewhat of a problem, and 6 = severe problem). A 17-item version of the PCSI was used for children aged 9 to 12 years old (PCSI-C); here, a 3-point scale was used to rate the severity of symptoms (0 = symptom not present, 1 = a little, and 2 = a lot).

Demographic Collection Form

Age, sex, and concussion history (number of previous concussions) were collected using a demographic collection form administered by research personnel. Type of primary sport (sport played most often and at the highest level) and level of play (competitive, house-league, or recreational) were also collected. Both child and youth athletes completed these forms at private desks, with graduate students/research assistants providing instruction and guidance where needed. Height and weight were collected and used to compute the participant's body mass index (BMI).

Procedure

Participants were recruited from various sports team organizations across the Greater Toronto Area via email and recruitment flyers. Informed consent was obtained from interested and eligible participants. Participants completed a 1-time baseline testing protocol²⁵ that included completion of the demographic form, applicable PCSI (PCSI-C or PCSI-Y), followed by measures of height, weight, and postural stability. The sway index for each participant was recorded under 4 sway conditions: (1) EO/FS, (2) EC/FS, (3) EO/US, and (4) EC/US. Each condition lasted 20 seconds, with 5 seconds of rest between each trial. The sway index recorded for each trial was used to determine the participant's postural stability under each of the 4 sway conditions.

Statistical Analysis

Linear regression analyses were performed to investigate the effects of age, sex, and concussion-related factors (ie, PCSI total score, number of previous concussions) on postural stability performance across 4 conditions (EO/FS, EC/FS, EO/US, EC/US) in healthy child and youth athletes. BMI was controlled for in the analyses as previous research suggests a trend toward decreased postural stability with increasing BMI.¹⁶ Regression analyses were conducted separately for the PCSI-C (9- to 12-year-olds) and PCSI-Y (13- to 18-year-olds) due to the variable number of items and scale ranges for these measures. Visual inspection of the outcome variables (performance on the 4 sway conditions) indicated leptokurtic distributions, with kurtosis values beyond literature recommendations of values between +2 and -2.¹¹ Thus, logarithmic transformations were applied to each of the sway outcome variables to enhance statistical inference from the models. As such, the assumptions of a linear regression (eg, normal distribution, homogeneity of variances, linearity) were met successfully. To further explore the influence of concussion-like symptoms on each sway condition, bivariate Spearman correlations were conducted for each of the 4 domains of the PCSI-C and PCSI-Y (physical, cognitive, emotional, fatigue) against each of the 4 sway conditions. The Statistical Package for the Social Sciences, version 22 (IBM Corp) was used to perform all analyses, and the threshold for statistical significance was set at $P \leq 0.05$.

RESULTS

All participants included in this study were athletes, with the majority of participants (85.5%) being categorized as participating in "representative" level sports (eg, competitive, rep, travel teams). A smaller minority (14.5%) played sports at the house-league or recreational level. As no exclusions were made to type of sport background, child and youth athletes in this study represented an array of sports: hockey (64%), soccer (14%), and other (22%). The "other" sports included team sports such as basketball and volleyball as well as individual sports such as cross-country running, tennis, and skiing. Table 2

provides a descriptive breakdown of postural stability performance across ages and sway conditions. Table 3 provides regression model estimates and significance values across child and youth athlete postural stability performances.

DISCUSSION

This study uniquely examined postural stability in the context of age, sex, and concussion-related factors (baseline concussion-like symptoms and concussion history) in child and youth athletes. In the context of child and youth athletes, this becomes particularly important as guidelines for returning to activity in this population are conservative²² and warrant a comprehensive approach to reduce the risk of reinjury.

Age and Postural Stability

In all the sway conditions, our findings suggest that older youth have better postural stability than younger youth, supporting our first hypothesis. Postural stability scores improve throughout childhood between the ages of 2 and 13 years old, as neuromuscular mechanisms for integrating sensory and motor processes for postural control are still developing.¹² Mechanisms for this continued development of postural stability include vestibular contributions, which have been speculated to be the slowest sensory system associated with postural stability, resulting in longer adaptation time and greater magnitudes of postural responses.¹³ The descriptive table provided in this study can act as a tool for clinicians in understanding the range of performance seen in athletes. In this children's outpatient rehabilitation hospital setting, clinicians use these postural stability values in conjunction with other clinical measures as a way to enhance the rigor of documentation in postinjury assessments and assist with interdisciplinary return-to-activity decision-making.

Sex and Postural Stability

Sex-based differences in postural stability performance were found between girls and boys in child athletes (9- to 12-year-olds), whereby girls had better postural stability compared with boys in EO/FS and EO/US (conditions in which visual information was present). Previous studies with nonathletic populations have found similar findings in that boys demonstrate significantly more sway than girls.^{8,10,19,21,23,29} Girls' vestibular systems may mature earlier than boys', with these differences identified between 7 and 10 years of age,¹³ and the onset of rapid growth spurts during puberty may regress sensorimotor mechanisms as youth adjust to the changes in their body, physically and hormonally.²⁴ It is important to note that while the BioSway considers visual and proprioceptive inputs in postural stability performance, all conditions are performed within a double-leg stance, and this may limit the ability to detect differences between males and females. These findings do not allow for conclusive recommendations on sex differences; however, they do suggest that further research regarding ecologically valid postural stability measurement is needed.

Table 2. Mean (standard deviation) of all postural stability (sway index) performances according to age and sway condition

| Sway Condition | Age, y | | | | | | | | | |
|----------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| | 9 (n = 13) | 10 (n = 59) | 11 (n = 113) | 12 (n = 149) | 13 (n = 191) | 14 (n = 160) | 15 (n = 107) | 16 (n = 64) | 17 (n = 29) | 18 (n = 4) |
| E0/FS | 0.707 (0.365) | 0.815 (0.281) | 0.712 (0.326) | 0.662 (0.253) | 0.628 (0.313) | 0.620 (0.293) | 0.560 (0.224) | 0.542 (0.244) | 0.486 (0.258) | 0.538 (0.131) |
| EC/FS | 0.873 (0.260) | 0.931 (0.416) | 0.807 (0.307) | 0.810 (0.365) | 0.756 (0.473) | 0.778 (0.596) | 0.654 (0.212) | 0.638 (0.223) | 0.638 (0.254) | 0.580 (0.252) |
| E0/US | 1.252 (0.460) | 1.364 (0.394) | 1.191 (0.389) | 1.141 (0.381) | 1.033 (0.331) | 1.006 (0.340) | 0.954 (0.280) | 0.994 (0.343) | 0.818 (0.291) | 0.732 (0.265) |
| EC/US | 2.019 (0.380) | 2.363 (0.671) | 2.153 (0.524) | 2.077 (0.550) | 1.979 (0.601) | 1.999 (0.522) | 2.018 (0.419) | 1.902 (0.496) | 1.953 (0.530) | 1.360 (0.171) |

EC/FS, eyes closed, firm surface; E0/FS, eyes open, firm surface; EC/US, eyes closed, uneven foam surface; E0/US, eyes open, uneven foam surface.

Table 3. Results of regression analyses according to Post-Concussion Symptom Inventory (PCSI) version^a

| | Sway Condition | | | | | | | |
|---|------------------------------|-----------------------------|-----------------------------|-----------------------------|------------------------------|------------------------------|-----------------------------|-----------------------------|
| | Log (E0/FS) | | Log (EC/FS) | | Log (E0/US) | | Log (EC/US) | |
| | PCSI-C | PCSI-Y | PCSI-C | PCSI-Y | PCSI-C | PCSI-Y | PCSI-C | PCSI-Y |
| Person factors B estimate (P value) | | | | | | | | |
| Age | -0.044 (0.0001) ^c | -0.021 (0.001) ^c | -0.023 (0.032) ^c | -0.022 (0.001) ^c | -0.035 (0.0001) ^c | -0.017 (0.0001) ^c | -0.024 (0.001) ^c | -0.011 (0.006) ^c |
| Sex | -0.038 (0.027) ^c | -0.002 (0.906) | -0.012 (0.515) | -0.027 (0.059) | -0.048 (0.001) ^c | 0.004 (0.695) | -0.011 (0.350) | 0.009 (0.334) |
| BMI | 0.008 (0.012) ^c | 0.001 (0.773) | 0.002 (0.572) | 0.004 (0.107) | 0.000 (0.891) | 0.003 (0.160) | 0.002 (0.355) | 0.005 (0.001) ^c |
| Concussion-related factors B estimate (P value) | | | | | | | | |
| PCSI total score | 0.004 (0.271) | 0.003 (0.002) | 0.009 (0.024) ^c | 0.003 (0.003) ^c | 0.003 (0.354) | 0.002 (0.008) ^c | 0.008 (0.002) ^c | 0.002 (0.019) ^c |
| No. of previous concussions | 0.023 (0.185) | -0.007 (0.408) | 0.002 (0.914) | -0.011 (0.210) | 0.018 (0.231) | -0.002 (0.814) | 0.006 (0.623) | 0.003 (0.613) |
| PCSI domain ^b r (P value) | | | | | | | | |
| PCSI Domain | NS | NS | NS | 0.093 (0.03) ^c | NS | NS | NS | 0.094 (0.028) ^c |

BMI, body mass index; EC/FS, eyes closed, firm surface; E0/FS, eyes open, firm surface; EC/US, eyes closed, uneven foam surface; E0/US, eyes open, uneven foam surface; NS, not significant; PCSI-C, PCSI version for children aged 9 to 12 years old; PCSI-Y, PCSI version for youth aged 13 to 18 years old.

^aRegression analyses were conducted separately for each version of the Post-Concussion Symptom Inventory (PCSI-C and PCSI-Y).

^bFollow-up correlational analyses on each of the physical, cognitive, emotional, and fatigue domains of the PCSI are depicted in the last row. NS signifies that all 4 domains were not significant in their relationship with postural stability performance. Where values are present, the physical symptom domain was significant.

^cStatistically significant main effect, where $P \leq 0.05$.

Baseline Concussion-Like Symptoms and Postural Stability

This study found that child and youth athletes who report more concussion-like symptoms (specifically, physical symptoms) during preinjury baseline testing demonstrate poorer performance on postural stability, especially during conditions that occlude visual inputs. Even without a concussion, the way an athlete feels at the time of baseline testing (eg, physical, cognitive, emotional, and fatigue-related symptoms) provides context to how they perform on objective physical measures. Although a weak relationship was demonstrated between physical symptoms and postural stability performance, being a healthy youth athlete may act as a protective factor in these concussion-like domains. For example, youth athletes, compared with nonathletes, show better psychosocial functioning, emotional well-being, self-efficacy, and psychological resilience.⁹ It may be plausible that sports participation lowers the amount of daily reported physical symptoms, and thus, does not have a strong influence on postural stability performance. These findings may act as a first step to relying on more objective measures in return-to-activity decision-making.¹⁷ These findings are in concordance with applying the multimodal assessment approach in preinjury/baseline testing. The combination of subjective and objective measures (while considering age and sex) build a holistic platform on which postconcussion scores can be compared. Overall, these findings provide a foundation for which to base future multimodal baseline studies and the potential utility in making reliable postconcussion comparisons.

History of Concussion and Postural Stability

History of concussion (number of previous concussions) did not affect postural stability performance in either the child or youth athlete samples. Sosnoff et al²⁸ also found no difference between individuals who had and did not have a history of concussion on performance of less-demanding postural measures such as standing with eyes open or closed; however, during more demanding tasks, such as standing on a sway-referenced surface with eyes closed, anterior-posterior sway increased for previously concussed individuals. Similarly, other studies found no differences in postural stability in a healthy group of youth athletes with and without a history of concussion.^{14,15}

Limitations

It is worth noting that BioSway reliability for the sway conditions has not yet been established for children and youth athletes and warrants investigation for future use. It is unclear whether a larger sample size would have yielded significant findings in concussion-like symptom domains. Regarding history of concussion, even though participants were healthy during the baseline protocol, specific information about the recency and time between previous concussions was not collected. This limits the interpretation of the findings of concussion history, and future studies should include a more detailed account of

previous concussion history. Additionally, the current method to assess postural stability may not have been challenging enough for an athlete population, as all conditions were assessed in double-leg stance. More dynamic assessment, which includes multidirectional single-leg stances, may have yielded different results. For example, previous studies have reported that postural stability deficits became prominent when previously concussed individuals faced more challenging postural stances such as compensatory or anticipatory postural responses.^{27,28}

CONCLUSION

This study found significant effects of age on postural stability performance in healthy child and youth athletes that are in line with the developmental trajectories in the integration of somatosensory, visual, and proprioceptive inputs. Sex-based differences were found whereby girls performed better than boys in the child athlete group; however, this difference was no longer present in the youth athlete group. Baseline/preinjury concussion-like symptoms reported by child and youth athletes also impacted postural stability whereby higher symptom report was associated with poorer postural stability. Taken together, this study highlights the variety of demographic and concussion-related factors that influence postural stability. Understanding physical measures, such as postural stability, in the context of development and other widely used clinical measures, such as symptom reports, can act to enhance interpretation of postconcussion comparisons.

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