Post-Concussion Postural Control Measures and Hypothesized Confounders: Implications for Adolescent Assessments

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INTRODUCTION AND BACKGROUND

The brain remains in a vulnerable state for an unknown period of time following a concussion.[1] Returning to activity while the brain is in this vulnerable state can be dangerous for young athletes.[1,2] There is a critical need to identify clinical measures and biomarkers that can effectively detect concussion-related impairments for younger athletes.[2]

Postural control is one measure of physical functioning that has been consistently demonstrated to be altered following concussion.[3-8] From a measurement standpoint, complexity characterizations of center-of-pressure (COP) trajectories (a representation of postural regulation) have been shown to be particularly useful for capturing subtle postural impairments that may remain following a mild head injury (Figure 1).[3-8] However, translation of these findings into clinical assessments is currently lacking, especially for the youth population.[2] In many cases, when youth are evaluated following mTBI, there are no baseline metrics available for comparison purposes. In addition, numerous confounders have been hypothesized to affect postural sway.[7]

PURPOSE

A critical next step is to examine the potential influence of the hypothesized confounders to determine how to best construct normative values to be used in clinical settings for adolescent athletes. Therefore, the purpose of this study was to examine the effects of age, sex, prior concussion history, days since injury, and ADHD status on a set of post-concussion postural control assessment metrics (Table 1).

TABLE 1. Overview of Postural Sway Variables

	General Description	Calculation	Interpretation
BESS	The Balance Error Scoring System (BESS) is a clinical balance test that utilizes 3 stances (bipedal, single leg, tandem) on two different surfaces (floor and foam) where errors in maintaining the position are recorded by a trained rater.	The total number of errors are summarized across the trials to yield a Total Score.	Higher scores are theorized to represent poorer postural control.
Path Length	A measure that represents the total distance the COP travels over the course of the trial.	Sum of the Euclidean distance between every consecutive point in the two-dimensional COP trajectory.	Increased path length is theorized to be indicative of decreased postural stability.
COP Area	Describes an enclosed space of the COP plot within which the COP of pressure oscillates for a large percentage of the time.	Determination of the best fitting ellipse, using the least squares criterion, to 95% of the data. The area of the ellipse is used to represent COP area.	Increased area is theorized to be indicative of decreased ability to process and integrate: visual, vestibular, and somatosensory information to optimally control posture
Sample Entropy	Quantifies the degree of irregularity (complexity) of small sub-sets of data sequences within a time series. Generally viewed along a continuum with higher scores indicating less repeatability or regularity in the time series (Figure 1).	A data point in the time series is considered recurrent with another data point if their positions are separated by less than a specified tolerance (r) for a chosen length of a string of data (m).	Healthy patterns display both: 1) regular patterns that theoretically reflect stable control and regulation and 2) randomness that is theorized to be indicative of an ability to accommodate physiologic challenges and adjust to perturbations. There is a theoretical "sweet spot" that is supposed to represent a healthy state that is both stable and able to accommodate changes.

METHODS AND MATERIALS

Participants

Participants for this study included 71 patients from a local outpatient hospital-affiliated concussion clinic (Table 2). Children and adolescents were eligible to be included in the study if they were referred to the physical therapy clinic for a post-concussion postural control evaluation and were successfully able to complete a BESS test and COP measurement trials on a force plate. Exclusion criteria for the study included a history of a pre-injury neurological diagnosis known to significantly affect postural control (e.g., vestibular disorder, brain tumor, hearing impairments) and a lower extremity or back injury within the last six months.

Data Collection

1. Balance Error Scoring System administered by a trained rater
2. Force plate assessment

- Subject stands on force plate with feet together and hands resting at sides (Figure 1)
- 2 trials (one eyes open, one eyes closed) on an AMTI force plate sampled at 100 Hz using Balance Clinic Software
- Trials lasting 2 minutes each

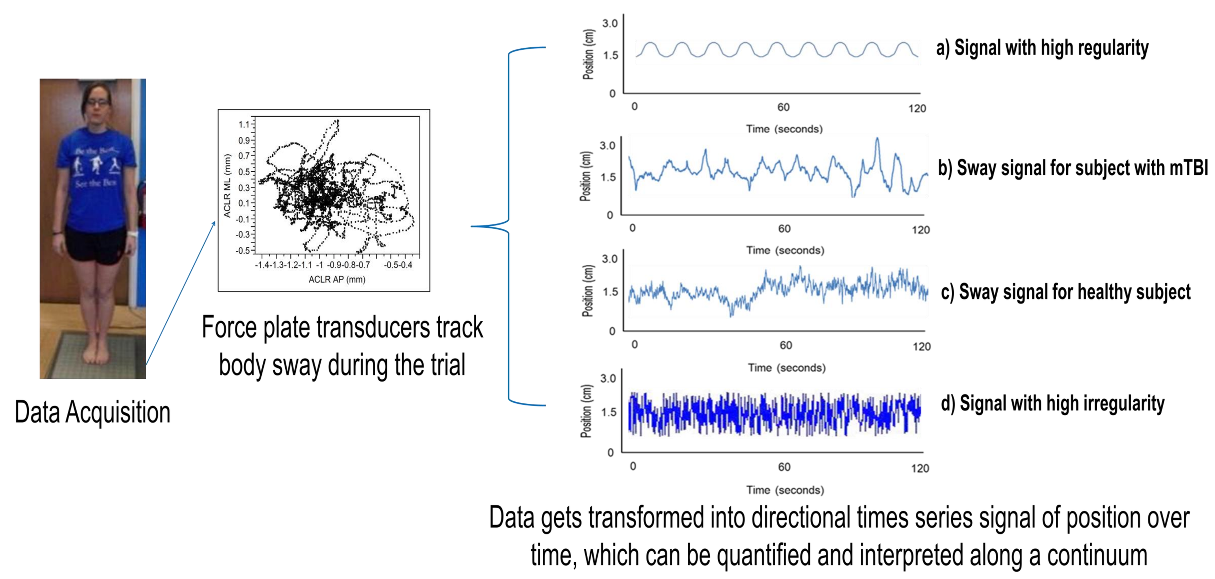

Figure 1. Data Acquisition and Interpretation Processes
This figure provides an overview of the data collection and interpretation processes with an emphasis on sample entropy (complexity metrics). The time series figures on the far right are set up to represent a mathematical and visual continuum of the regularity of a time series. Patterned sequences in the COP data can range from highly structured, deterministic and predictable (Figure 1a) to completely unstructured, random and unpredictable (Figure 1 d). COP data typically falls somewhere within this continuum. Numerous studies have indicated that postural sway complexity may become more regular following mTBI (Figure 1b compared to Figure 1c).

ANALYSES

Custom MATLAB (MathWorks, Inc) code was used to calculate the postural sway metrics for each trial for each subject. These variables included: Sample entropy in the anterior-posterior direction (SampEn-AP), Sample entropy in the medial-lateral direction (SampEn-ML), Path Length, and COP Area. In order to avoid oversaturation of data points, which can bias entropy measures, the time series were down-sampled from 100 Hz to 50 Hz. Based on methods described in Ramdani et al.,[9] the optimal recurrent data point template (m) and the threshold of similarity for data points (r) for SampEn measures were identified as 2 and 0.20, respectively.

Pearson product-moment correlation coefficients were calculated to test for potential associations between the continuous participant characteristics. Spearman correlation was used to test the association between symptoms and the postural control variables. Standard multiple regression was used to model the extent to which the postural metrics could be explained by age, history of prior concussion(s), pre-injury diagnosis of ADHD, and days since injury accounted for the variance in the postural sway variables. Preliminary analyses were conducted to ensure the assumptions of normality, linearity, multicollinearity and homoscedasticity were met. Models were tested at the nominal α=0.05 level.

RESULTS

TABLE 2. Sample Characteristics

Variable	Mean (SD)	Median (IQR)	*f*
Age	14.14 (2.44)		
Gender			
Male			42 (59.2%)
Female			29 (40.8%)
Days Since Injury	11.02 (7.17)		
PCSS Severity scores		14.50 (28.00)	
History of Prior Concussion			
No Concussion			56 (78.87%)
History of 1 Prior Concussion			12 (16.90%) `
History of 2 Prior Concussion			3 (4.23%)
ADHD			10 (14.08%)

Note: AD: Standard deviation; IQR: Inter-quartile range

The correlational analyses revealed a significant negative correlation with age and all of the postural sway variables for both the eyes open and eyes closed conditions except SampEn-AP for both conditions (Table 3). A significant correlation was also observed for SampEn-ML eyes open and number of symptoms and SampEn-ML eyes closed and days since injury. Preliminary analyses revealed no violations of the assumptions. Only age was a statistically significant predictor of any postural control variables. None of the other independent variables (sex, prior concussion, ADHD) predicted a significant amount of the variance in any of the postural control measures.

RESULTS CONTINUED

TABLE 3. Correlation Coefficients for Postural Sway Variables

Postural Sway Variable	Age	Symptom Severity	Number of Symptoms	Days Since Injury
BESS Total	-.38**	-0.10	-.06	.0.19
Eyes Open Condition				
Path Length (cm)	-.64**	-.16	-.19	.06
COP Area (cm^2)	-.32**	-.04	-.13	-.06
SampEn-AP	-.22	-.05	-.09	.21
SampEn-ML	-.51**	-.23	-.26**	.16
Eyes Closed Condition				
Path Length (cm)	-.41**	-.03	-.05	.16
COP Area (cm^2)	-.30*	-.07	-.14	.01
SampEn-AP	-.13	.12	.10	.11
SampEn-ML	-.27*	-.11	-.11	.34**

***p-value < .05, ** p-value < .01**

CONCLUSIONS AND CLINICAL RELEVANCE

Postural control is a critical component of the post-concussion assessment battery of tests. Age, gender, ADHD status and prior history of concussion have all been theorized to serve as potential confounders for post-concussion postural control assessments. In the current study, however, only age appeared to consistently and significantly influence scores on common post-concussion postural control assessments. This study demonstrates that age is a critical factor that needs to be accounted for in order to improve the clinical appropriateness and utility of current post-concussion postural control assessments for children and adolescents.

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