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Short communication

Recovery of static stability following a concussion

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ABSTRACT

The purpose of this study was to use centre of pressure (COP) measurements to determine if static balance deficits had recovered when concussed athletes were cleared to return to play. Nine concussed varsity football players were matched with nine teammates who served as controls. Static balance in the anterior–posterior (A/P) and medial–lateral (M/L) directions was assessed during quiet stance with eyes open and eyes closed. Results showed that concussed football players displayed greater A/P COP displacements in the acute phase, which recovered by RTP; however, COP velocity remained elevated compared to controls even at RTP, particularly in the A/P direction. This balance control deficit in the A/P direction may suggest vestibular impairment, likely due to poor sensorimotor integration of the lateral vestibulospinal tract. The observed persistence of balance control deficits in concussed football players at RTP are usually undetected by traditional assessments because the current study used higher-order COP analysis. Future RTP balance measures may want to incorporate higher-order measures of balance.

1. Introduction

Concussion is a complex pathophysiological process affecting the brain induced by traumatic biomechanical forces [1]. A cardinal sign of concussion is loss of balance control [1]. The Balance Error Scoring System (BESS) is a component of the Sport Concussion Assessment Tool 2 (SCAT2) that reveals static balance deficits immediately after concussion; however these deficits typically recover within 3–5 days post injury [2]. Recent evidence suggests that learning effects [4] and decreased sensitivity over time [5] challenge the BESS reliability [3]. More objective measures to assess the recovery of balance impairments post-concussion are therefore warranted.

Centre of pressure (COP) provides an indirect but valid and objective measure of centre of mass (COM) movement and balance control [6]. COP measurements are sensitive enough to detect impaired balance two years after traumatic brain injuries from motor vehicle accidents or falls [7] and while this population may reflect a more serious brain injury, the measure is transferable to concussed populations. The purpose of the current study was to use COP characteristics to determine whether static balance deficits have fully recovered when concussed athletes have returned-to-play (RTP). We hypothesized that COP measures would show persistent balance control deficits in athletes upon RTP following concussion.

2. Methods

2.1. Participants

Nine varsity football players with concussion (Table 1) were evaluated using the SCAT2 and recruited for participation in the study by the team's Certified Athletic Therapist. Concussed players (CONC) were age- and position-matched with nine healthy teammates who served as controls. Exclusion criteria included any medication or injury that would affect normal balance control or gait, controls also could not have had a concussion within the previous 12 months. This study that was approved by the Institutional Research Ethics Board and participants provided written informed consent.

2.2. Experimental protocol

CONC participants were tested during the acute phase (symptomatic yet able to perform task) and at RTP (Table 1). Controls were tested at a single time point that coincided with the acute phase of their concussed counterparts. Participants stood on a Bertec^{TM} forceplate (Columbus, OH) with their feet together, hands at their sides. To assess static balance during quiet stance, force was sampled at 50 Hz for 3 trials with the eyes open and 3 trials with the eyes closed. Each trial lasted 60 s and the order of visual conditions was randomized. Participants also completed a

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Table 1
Characteristics of concussed and control participants (mean ± standard deviation, unless otherwise stated).

	Control	Concussed	
		Acute	RTP
Age	20.28 (±1.47)	20.16 (±1.19)	
Total SCAT2 symptom score	3.89 (±9.25)[a]	34.89 (±22.08)[a,b]	1.22 (±1.92)[b]
Range of SCAT2 symptom score	0–28	4–67	0–5
No. of days since tested concussion	–	5.33 (±4.33)	26.44 (±14.03)
Range of days since tested concussion	–	1–13	10–48
No. of previous concussions	0.91 (±1.38)	0.67 (±0.87)	
Range of no. of previous concussions	0–4	0–2	
No. of months since previous concussion	33.00 (±20.49)	24.25 (±20.98)	

[a] Acute > Control ($t_{(16)} = 3.89$, $p = 0.0013$).
[b] Acute > RTP ($t_{(8)} = 4.81$, $p = 0.0013$).
Control = RTP ($t_{(16)} = -0.87$, $p = 0.4097$).

health history questionnaire that included the SCAT2 symptom evaluation checklist on each testing day.

2.3. Data analysis

The first 15 s of forceplate data was not analysed. Root mean square (RMS) of COP displacement and velocity were calculated in both the anterior–posterior (A/P) and medial–lateral (M/L) plane. Separate mixed model ANOVAs (2 visual conditions × 2 groups) were performed for each dependent measure to compare CONC to controls in the acute phase and at RTP. Tukey's HSD post hoc analysis was used to detect differences between means when significant ($p < 0.05$) main effects or interactions were identified.

3. Results

3.1. RMS COP displacement

During the acute phase, there was an interaction between visual condition and group ($F(1,16) = 6.56$, $p = 0.021$) in the A/P direction. Concussed athletes had greater COP displacement with eyes closed than with eyes open and compared to controls with eyes closed (Fig. 1B). COP displacement was not different between visual conditions for the controls. There were trends toward greater COP displacement in CONC compared to controls ($p = 0.05$) and higher COP displacement with eyes closed when CONC and controls' data were pooled ($p = 0.061$). There were no differences in COP displacement in the M/L direction (Fig. 1A). At RTP there were

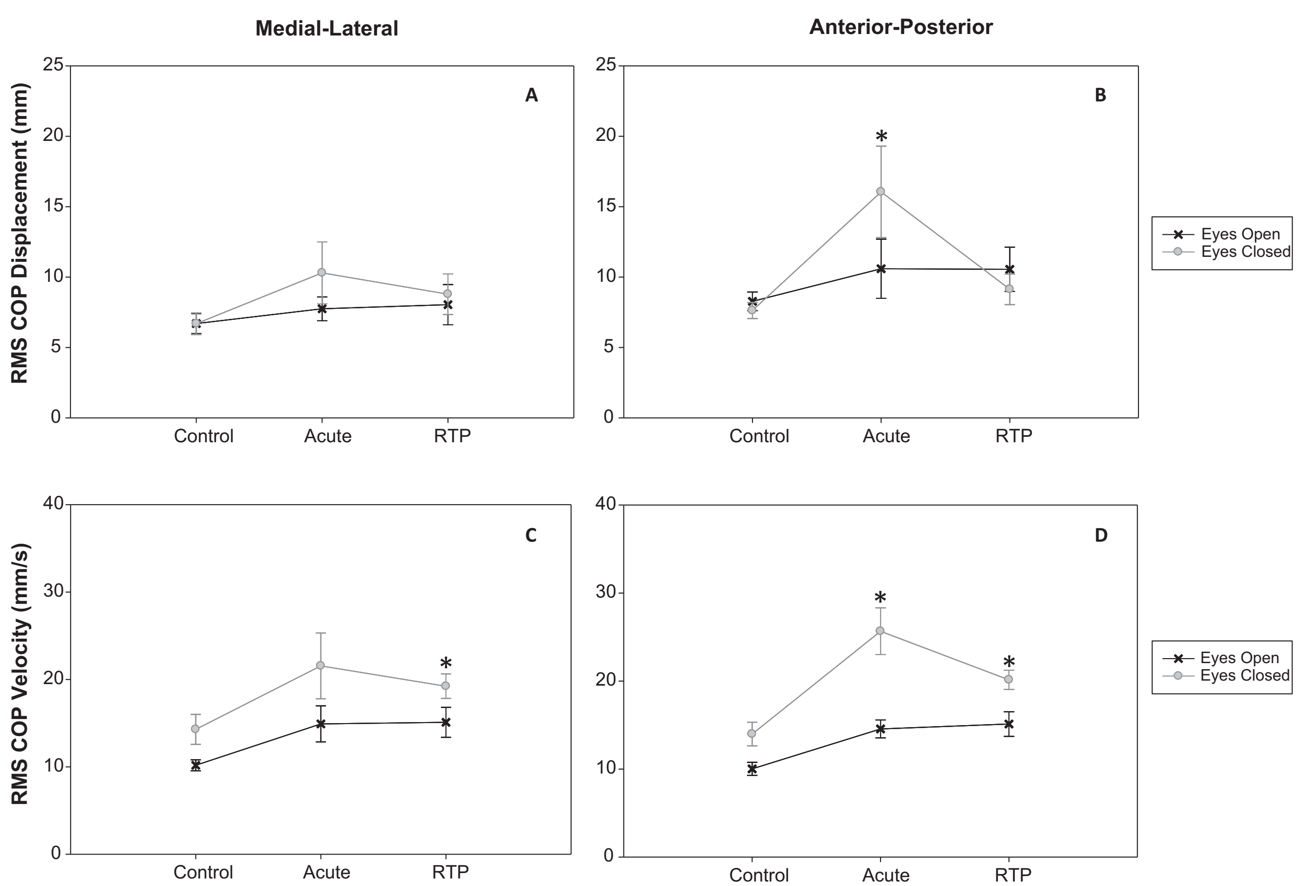

Fig. 1. (A) Medial–lateral COP displacement, (B) anterior–posterior COP displacement, (C) medial–lateral COP velocity, (D) anterior–posterior COP velocity. Error bars indicate standard error of mean for each group. *Indicates significant difference from controls at $p < 0.05$.

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no differences in combined A/P and M/L COP displacement between CONC and controls.

3.2. RMS COP velocity

In the acute phase, there were main effects of group ($F(1,16) = 21.88$, $p = 0.0003$) and visual condition ($F(1,16) = 25.11$, $p = 0.0001$) in the A/P direction and an interaction between visual condition and group ($F(1,16) = 5.70$, $p = 0.0297$; Fig. 1D). CONC had faster moving COP with eyes closed compared to eyes open and faster than controls with eyes closed. In the M/L direction, there was a main effect of vision ($F(1,16) = 12.69$, $p = 0.0026$), COP velocity was greater with eyes closed than eyes open. There was a trend toward a greater COP velocity in CONC compared to controls ($p = 0.058$) when visual conditions were pooled.

On average, CONC returned to play 26.44 ± 14.03 days after concussion. At this time there were main effects of group ($F(1,16) = 15.27$, $p = 0.0013$) and vision ($F(1,16) = 29.22$, $p < 0.0001$) in the A/P direction. CONC had higher COP velocity than controls across visual conditions. With eyes closed, COP velocity was faster than with eyes open. Likewise, M/L COP velocity was different between groups ($F(1,16) = 7.08$, $p = 0.0171$) and visual conditions ($F(1,16) = 23.47$, $p = 0.0002$). CONC also had greater COP velocity than controls and COP velocity was greater with eyes closed compared to eyes open (Fig. 1C).

4. Discussion

The key finding of this study was that balance control of concussed athletes was not fully recovered upon return to play as indicated by increased velocity of COP. This deficit was evident despite recovery of COP displacement and reduction of reported symptoms. Clinically, this is problematic given that traditional RTP assessments rely on reports of symptoms and tests that are more related to gross motor control of balance control.

Displacement is a first-order variable coding position of the system, whereas velocity and acceleration represent higher order variables coding direction and intensity of movement [8]. As such, displacement is controlled via somatosensory feedback while velocity and acceleration require greater sensory integration from the visual and vestibular systems [8]. Without vision, the vestibular and somatosensory inputs must be up-regulated to maintain balance [9,10]. During the acute post-concussion phase, impaired vestibular and visual input to the CNS would likely be reflected by increased COP displacement and velocity compared to healthy controls. In the current study, COP displacement recovers while COP velocity remains elevated when concussed athletes return to play. This would suggest recovery of the somatosensory system, but a persistent impairment in the vestibular system.

During locomotion, a COP that moves faster usually indicates a faster moving COM. Accordingly, concussed athletes combat poor balance control by walking slower to allow the COP adequate time to corral the COM [11,12]. During static balance, however, increased COP velocity may reflect a greater need to control COM displacements. In this sense, COP velocity is a very good predictor of balance because it represents the central anticipatory adjustments to maintain stability [8]. Thus, a fast moving COP during static balance may indicate poor balance (COM) control.

A second key finding was that balance deficits were more pronounced in the A/P direction. During quiet standing, A/P movement is primarily controlled by ankle extensors [13] which receive input from the descending lateral vestibulospinal tract (VST) [14]. Following concussion, damage to the vestibular system could result in impairments to the lateral VST. This would lead to compensatory torques about the ankle and greater COP displacement in the A/P direction.

Symptom evaluation and possibly subjective balance assessments may not be sensitive enough to detect deficits in balance control that are present in concussed athletes who have returned to play. Therefore, development of objective balance assessment tools is required to ensure that athletes are not returned to play with sensorimotor impairments.

Acknowledgement

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Conflict of interest statement

None.

Appendix A

See Table A1.

Table A1
Individual characteristic data by group.

Group	Total SCAT2 symptom score	No. of days since latest concussion	No. of previous concussions
CONT			
1	0	–	0
2	0	–	1
3	0	–	0
4	28	–	4
5	0	–	3
6	1	–	0
7	0	–	0
8	0	–	0
9	6	–	1
CONC–acute			
1	37	1	0
2	4	8	0
3	67	13	0
4	44	11	1
5	5	3	1
6	29	3	0
7	21	4	2
8	51	4	2
9	56	1	0
CONC–RTP			
1	0	15	–
2	0	34	–
3	5	41	–
4	1	34	–
5	1	11	–
6	0	10	–
7	0	30	–
8	4	48	–
9	0	15	–

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