International Journal of Psychophysiology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Sub-concussive trauma, acute concussion, and history of multiple concussions: Effects on quiet stance postural control stability

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ARTICLE INFO

Keywords:
Sport concussion
Sub-concussive impacts
Concussion history
Postural control
Quiet stance

ABSTRACT

Although balance control has been studied extensively following acute concussion, little is known regarding repetitive sub-concussive head impacts or chronic exposure to multiple concussive events. Quiet stance postural control was characterized in contact sport athletes at pre-season ($n = 135$) and post-season ($n = 48$) to evaluate the effects of subconcussive trauma to the head. To determine the impact of acute concussion on postural control, athletes diagnosed with a concussion during the season ($n = 12$) were tested at 72-h, 2-weeks, and 1-month post-injury. Because only 4 of the concussed athletes completed baseline testing, control athletes ($n = 12$) matched for sport, age, body mass index (BMI), and previous concussion history served as a comparison group. Finally, the effects of previous concussion history on quiet stance postural control were determined by comparing pre-season data in contact sport athletes with either zero (Hx^0, $n = 50$) or three or more (Hx^{3+}, $n = 25$) previous concussions. A force plate was used to compare changes in centre-of-pressure root-mean-square displacement (RMSdisp) and mean-velocity (COPvel) in the anterior/posterior (AP) and medial/lateral (ML) directions. One-minute trials were performed with feet hip-width apart, hands-on-hips, and A) eyes-open and B) eyes-closed. Biomechanical head-impact exposure (impacts over 10 g) was indexed over the season using mastoid-fixed impact sensors. In acutely injured athletes, repeated-measures ANOVA revealed a significant effect of time for RMSdisp AP with increased displacement at 2 weeks compared to 72 h ($p = 0.008$, 95% CI: -0.180, -0.310 cm). No other COP variables were affected by acute concussion. Moreover, there was no effect of concussion history or repeated sub-concussive impacts on any quiet stance metric. Additionally, head-impact exposure metrics were not correlated with COP metrics. Taken together, the data suggests alterations in COP sway during quiet stance persist in the acute 2-week period after injury. These findings were not present with either a history of multiple concussions or exposure to sub-concussive head impacts indicating acute concussion does not have appear to have long term effects for these measures.

1. Introduction

In contact sports (e.g. football and hockey), tackling and checking are integral components of game play; however, these aspects elevate the risk of injury, including concussions. Langlois and colleagues (Langlois and Rutland-Brown, 2006) estimated 1.6 to 3.8 million sport-related concussions occur annually in the United States, with approximately 10–25% of contact sport athletes sustaining a concussion every season (Echlin et al., 2010). Whereas this may seem high, it is thought to underestimate the true incidence rates due to athlete non-disclosure (Kerr et al., 2015a, 2015b), lack of objective diagnostic tools (Broglio et al., 2007), and a relative dearth of diagnostic skills training in health care professionals (Boggild and Tator, 2011; Donaworth et al., 2016).

A concussion is a physiological brain injury occurring as a result of an impact to either the head or body that transmits forces to the brain, triggering a variety of somatic, cognitive and emotional symptoms, as well as deficits in postural control (Guskiewicz, 2003; McCrory et al., 2013; Reed-Jones et al., 2014; Ruhe et al., 2014). From a biomechanical perspective, in order to maintain upright posture during static or quasi-static activities (such as quiet stance), the vertical projection of the whole-body centre-of-mass (COM) must fall within the limits of the base of support. To accomplish this, adjustments in the underfoot centre-of-pressure (COP) are used to guide the COM towards equilibrium. Larger and/or faster movements of the COP (and by extension

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https://doi.org/10.1016/j.ijpsycho.2018.03.005
Received 2 March 2017; Received in revised form 2 March 2018; Accepted 6 March 2018

the COM) have typically been viewed as a worsening of postural control (Reed-Jones et al., 2014; Winter, 1995).

Disruptions to postural stability have been shown immediately following concussive impacts and are thought to persist at least 3–5 days post-injury (Guskiewicz, 2011; Guskiewicz et al., 2001, 1996; McCrea et al., 2003; Reed-Jones et al., 2014). More recently, balance disturbances (e.g. increased COP velocity) have been observed one month or more following injury, (Powers et al., 2014) at which time the vast majority of athletes (~90%) have typically returned to their sport (McCrea et al., 2012; Powers et al., 2014). Despite previous reports of a dose-response relationship between the number of prior concussions and future risk of incurring a subsequent concussion (Guskiewicz et al., 2003) little is currently known regarding the potential for cumulative long-term deficits in postural control following multiple concussions. Wasserman and coworkers (Wasserman et al., 2015) observed that those who experienced recurrent concussions had a greater proportional loss of balance acutely than athletes who experienced their first concussion. Finally, whereas multiple groups have reported alterations in brain structure and function following exposure to repetitive sub-concussive head impacts (Rodrigues et al., 2016), controversy remains as to if such trauma impairs balance (Broglio et al., 2004; Haran et al., 2012; Schmitt et al., 2004; Virgilio et al., 2016). As of yet, no research has investigated the influence of a season of sub-concussive head impacts (such as those sustained in contact sports) on quiet stance postural control. Thus, further characterization of the effects of long-term sport-related head trauma and sub-concussive incidents on balance control is warranted.

The purposes of this study were to use COP displacement and velocity measures as a probe of postural stability (Valovich McLeod and Hale, 2015) to: 1) characterize alterations in quiet stance postural control acutely following a concussion through initial month of recovery; 2) determine if deficits in postural control persist in those with multiple (3+) previous concussions, and; 3) determine the effect of one athletic season of sub-concussive head impacts on quiet stance postural control. It was hypothesized that quiet stance postural control would be impaired acutely – manifested as increased COP displacement and velocity – with deficits persisting longer than the previously reported 3–5 days (Guskiewicz, 2011; Guskiewicz et al., 2001, 1996; McCrea et al., 2003; Reed-Jones et al., 2014). Second, it was hypothesized individuals with a history of 3+ concussions would exhibit greater COP displacements and velocity during quiet stance than those with no previous concussion history (De Beaumont et al., 2011; Degani et al., 2017). Lastly, we hypothesized larger COP movements (displacement and velocity) will be observed following a season of sub-concussive head impacts correlated with the degree of impact exposure.

2. Materials and methods

2.1. Study design

135 male participants were recruited from local elite junior football, hockey, and rugby teams during the 2015/2016 season (demographics presented in Table 1). Measures of COP displacement and velocity were obtained while participants stood on a force plate (see Experimental Protocol). In addition, participants completed the Sport Concussion Assessment Tool 3 (SCAT3) (McCrory et al., 2013). To determine the effect of acute concussion on postural control, athletes diagnosed with a concussion (McCrory et al., 2013) by team physicians during the competitive season ($n = 12$) completed testing at 72-hours, 2-weeks, and 1-month post-injury. Because only 4 concussed athletes completed baseline testing, athletes (n = 12) matched for sport, age, body mass index (BMI), and previous concussion history (see Table 2) served as controls. To determine the effect of previous concussion history on postural control, data from a pre-season baseline testing session were stratified into two groups: i) no previous history of concussion (Hx^0, $n = 50$); and ii) three or more previous concussions (Hx^{3+}, $n = 25$). Many previous studies examining the effect of concussion history have compared participants with 1+ vs. no concussions. Others have made the comparison between multiple vs. no concussions (e.g., De Beaumont et al., 2007; List et al., 2015; Moser et al., 2005) and we decided to use this approach in the present study. Finally, to determine the effect of a season of contact sport on postural control, a subset of athletes who did not sustain a concussion during the season returned for post-season testing ($n = 48$) within two weeks following the end of regular season play. To control for effects of training across one season of elite athletics in evaluating the effects of sub-concussive head trauma, a group of non-contact sport athletes ($n = 15$) also underwent pre- and post-season testing. Fig. 1 shows a visual representation of the study design. Exclusion criteria included a significant history of cardiorespiratory, cerebrovascular, neurological, or severe neurodevelopmental disorder. No subjects were excluded based on these grounds. All subjects underwent familiarization of testing procedures, and provided written informed consent prior to participation in the study, which was approved by the University of British Columbia Clinical Research Ethics Board.

Table 1
Values represented as mean ± standard deviation. Each group that was assessed is represented by sport.

Participants	Sport	Age (years)	Age Range (years)	BMI (kg/m^2)	Concussion History
All participants (n = 135)					
n = 92	Football	19.54 ± 1.49	17–22	28.31 ± 4.63	1.78 ± 2.54
n = 37	Hockey	18.48 ± 1.04	17–20	25.01 ± 1.25	1.05 ± 1.77
n = 6	Rugby	21.33 ± 2.07	18–24	27.13 ± 3.17	2.33 ± 2.58
Acutely concussed (n = 12)					
n = 5	Football	20.60 ± 0.55	20–21	29.02 ± 3.58	1.20 ± 1.31
n = 7	Hockey	17.86 ± 1.07	17–20	24.87 ± 1.27	1.14 ± 1.68
No previous concussion (n = 50)					
n = 30	Football	19.57 ± 1.7	17–22	30.34 ± 5.65	0 ± 0
n = 18	Hockey	18.50 ± 0.86	17–20	24.86 ± 1.05	0 ± 0
n = 2	Rugby	22.00 ± 1.41	21–23	29.60 ± 4.32	0 ± 0
3+ Previous concussions (n = 25)					
n = 20	Football	19.95 ± 1.67	17–22	28.49 ± 4.09	5.15 ± 3.60
n = 3	Hockey	18.33 ± 2.08	17–20	25.83 ± 0.93	5.33 ± 4.04
n = 2	Rugby	22.50 ± 2.12	21–24	27.62 ± 0.65	5.50 ± 0.71
Post-season follow-up (n = 48)					
n = 44	Football	19.81 ± 1.45	17–22	29.01 ± 5.36	1.59 ± 1.56
n = 4	Hockey	18.75 ± 0.50	18–10	24.76 ± 0.54	1.00 ± 1.41
Non-contact controls (n = 15)					
n = 15	Various	20.20 ± 1.86	17–25	22.07 ± 2.59	0.20 ± 0.56

Table 2
Values represented as mean ± standard deviation. Participants were matched on sport, age, BMI, and previous concussion history. Independent T-tests were used to assess potential differences between groups. Concussed and matched athletes were not significantly different in age ($p = 0.45$), BMI ($p = 0.75$), or concussion history ($p = 0.76$).

Participants	Age (years)	BMI (kg/m^2)	Concussion history
Acutely concussed athletes			
n = 12	19.00 ± 1.65	26.60 ± 3.18	1.16 ± 1.47
Matched athletes			
n = 12	19.50 ± 1.57	26.19 ± 3.18	1.00 ± 1.20

2.2. Experimental protocol

During testing, participants completed one 60-s quiet stance trial for each of two conditions (eyes-open and eyes-closed) after being given the following instructions: “Stand quietly on the force plate with your hands on your hips and your feet hip width apart.” Stance width was not normalized or measured; rather we relied on participants to self-