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Cognitive and postural precursors of motion sickness in adolescent boxers

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ABSTRACT

Athletic head trauma (both concussive and sub-concussive) is common among adolescents. Concussion typically is followed by motion sickness-like symptoms, by changes in cognitive performance, and by changes in standing body sway. We asked whether pre-bout body sway would differ between adolescent boxers who experienced post-bout motion sickness and those who did not. In addition, we asked whether pre-bout cognitive performance would differ as a function of adolescent boxers' post-bout motion sickness. Nine of nineteen adolescent boxers reported motion sickness after a bout. Pre-bout measures of cognitive performance and body sway differed between boxers who reported post-bout motion sickness and those who did not. The results suggest that susceptibility to motion sickness-like symptoms in adolescent boxers may be manifested in characteristic patterns of body sway and cognitive performance. It may be possible to use pre-bout data to predict susceptibility to post-bout symptoms.

Sports, such as soccer, American football, and boxing, are associated with head trauma, including concussive and sub-concussive impacts. Sport participation is most common among adolescents (i.e., post-purbertal children) and, in part for this reason concussion is more common among adolescents than other age groups [1]. Many studies have examined phenomena relating to head trauma in adults [2], or in mixed adult-adolescent samples, typically in collegiate settings [3]. Fewer studies have examined these issues specifically in adolescents [4,5].

Athletic head trauma is associated with degraded cognitive performance [5,6] and with changes in standing body sway [7]. Athletic head trauma is also associated with dizziness and nausea [2,8]. Dizziness and nausea are associated with motion sickness, and boxers (as one example) often refer to post-bout symptoms as *motion sickness* [9]. In a recent study of boxers 18–34 years old (mean = 25.6 years, SD = 5.1 years), the experience of motion sickness that occurred after boxing was related to pre-bout measures of body sway [10]. In the present study, we asked whether post-bout motion sickness might be related to pre-bout measures of both cognitive performance and body sway in adolescent boxers.

Our research relating body sway to head trauma was inspired, in part, by research relating body sway to visually induced motion sickness. Before exposure to nauseogenic visual motion stimuli body sway sometimes differs between participants who later (i.e., after exposure) report motion sickness and those who do not. Such effects have been observed in mixed adult-adolescent samples [11] and in 10-year-old children [12]. These effects are consistent with the postural instability theory of motion sickness, in which unstable control of body posture is claimed to be a necessary and sufficient precondition of motion sickness [13]. Stoffregen [14] argued that similar effects might exist in relations between pre-exposure body sway and other sources of motion sickness-like symptoms, such as concussive and sub-concussive head trauma.

In children, young and elderly adults body sway is modulated in relation to the demands of cognitive tasks, such as reading [15–17]. Body sway displaces the head and eyes, and these natural displacements can influence the performance of cognitive tasks that require precise stabilization of the head and eyes [18]. Links between body sway and motion sickness, on the one hand, and between body sway and cognitive performance, on the other, raise questions about possible relations between all three. Research documenting head trauma in adolescents has not included data on

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body sway, cognitive performance, or on relations between cognitive performance and post-traumatic subjective experiences, such as motion sickness [4,5]. Following previous studies, among adolescent boxers we predicted that pre-bout standing body sway would differ during performance of different cognitive tasks [10,15–18]. Separately, we predicted that pre-bout cognitive performance would differ between boxers who reported post-bout motion sickness and those who did not.

We assessed adolescent boxers before and after they participated in a regulation sparring bout. Before bouts, we measured cognitive performance and standing body sway. After bouts, we measured motion sickness incidence and symptom severity. In pre-bout postural testing we also varied stance width (the distance between the heels), which affects standing body sway [19] and susceptibility to motion sickness [11]. The design, independent, and dependent variables were the same as in Chen et al. [10], who used older boxers as participants.

1. Methods

Testing was conducted at a national sparring event at the Bei-Ling High School, Taipei, Taiwan. Boxing was supervised by three referees and a ringside physician.

1.1. Participants

Nineteen boxers participated from middle schools and high schools in Taiwan, with boxing experience from 2 to 6 years. Sixteen were male and three were female, with mean age 15.6 years (SD = 1.1 years), mean height of 164.7 cm (SD = 5.8 cm), and mean weight of 53.3 kg (SD = 7.8 kg). Each participant reported that they had never been diagnosed with a concussion. Boxers were selected from the middle school and high school groupings (as defined by the Taipei Amateur Boxing Association), which was limited to boxers 13–16 years of age. By Taipei Amateur Boxing Association rules, boxers could compete only against other members of their age group; accordingly, none of our participants had ever competed against adult boxers.

1.2. Apparatus

Data on body sway were collected using a force plate (AccuswayPlus, AMTI). We recorded the kinematics of the center of pressure (COP), sampled at 60 Hz in the AP and ML axes.

1.3. Procedure

Participants were tested ringside before and after their first sparring bout. We evaluated the incidence of motion sickness based on participants' responses to a yes/no, forced-choice question, *Are you motion sick*? Participants answered this question before warm-up, after warm-up, and post-bout. Participants were assigned to Sick and Well groups based solely on their post-bout responses to this forced-choice question. We evaluated the severity of motion sickness symptoms using the Simulator Sickness Questionnaire, or SSQ [20]. The SSQ is a standardized questionnaire that assesses the severity of 16 different symptoms (e.g., nausea, disorientation), which was translated into Chinese.

Participants first completed the informed consent procedure, after which they completed the SSQ and the first session of cognitive/postural testing. Participants then went through a 30 min warm-up routine comprising jogging, stretching, and practice punches, after which participants completed the second SSQ and the second session of cognitive/postural testing.

Cognitive/postural testing consisted of 6 trials, each 60 s in duration, standing on the force plate. We used a 2 (cognitive tasks: inspection vs. search) × 3 (stance width = 5 cm vs. 17 cm vs. 30 cm) design with one trial per session (before vs. after warm-up) in each of six conditions for a total of 12 trials per participant. The order of conditions was counterbalanced across participants. To control stance width, participants stood with their feet on marked lines on the force plate.

Targets for the cognitive tasks were sheets of white paper 13.5 cm × 17 cm mounted on rigid cardboard [16]. In the Search task the target was one of four blocks of English text, each comprising 13 or 14 lines of text printed in a 12-point sans serif font. Prior to each trial the participant was given a target letter (A, R, N, or S) and asked to count the number of times the target letter appeared in the text. After each trial, participants reported the number of letters counted. In the Inspection task, the target was a blank sheet of white paper; participants were instructed to keep their gaze within the borders of the target.

Sparring bouts consisted of 3 rounds, with a 1 min break between rounds. The duration of each round was 3 min for males, and 2 min for females. Bouts could be terminated early by the referee. SSQ3 was administered within 20 min after bouts.

1.4. Analysis of postural data

We assessed movement magnitude in terms of positional variability, which we defined operationally as the standard deviation of COP position. We assessed the temporal dynamics of movement using detrended fluctuation analysis (DFA), which describes the relation between the magnitude of fluctuations in COP position and the time scale over which those fluctuations are measured [21]. DFA has been used in studies relating body sway to aging [22], to cognitive performance [23], and to motion sickness [11]. We did not integrate the time series before performing DFA. We conducted inferential tests on α, the scaling exponent of DFA. The scaling exponent is an index of long-range autocorrelation in the data, that is, the extent to which COP positions are self-similar over different time-scales.

We conducted 2 × 2 × 2 × 3 repeated measures ANOVAs on factors Task (inspection vs. search), warm-up (before vs. after), stance width (5 cm vs. 17 cm vs. 30 cm) and Group (Sick vs. Well). Separate analyses were conducted for sway in the AP and ML axes. We used the Greenhouse-Geiser correction and, where relevant, we report the fractional degrees of freedom that this correction entails. We estimated effect size using the partial η^2 statistic.

2. Results

2.1. Subjective reports

Before and again after warm-up, each participant stated that they were not motion sick. After boxing, nine participants stated that they were motion sick (47.4%), and were assigned to the Sick group. Of these, 3 won their bouts and 7 lost. Ten participants stated that they were not motion sick and were assigned to the Well group. Of these, 6 won their bouts and 4 lost.

Data on symptom severity are summarized in Fig. 1. Before warm-up, SSQ scores did not differ between the Well and Sick groups, Mann–Whitney $U = 48.5$, $p = .741$ (two-tailed). After warm-up, SSQ scores were higher in the Sick group than in the Well group, $U = 76$, $p = .009$ (two-tailed). After boxing, SSQ scores were higher among participants in the Sick group than in the Well group, $U = 73$, $p = .009$ (one-tailed).

Within groups, we used the Wilcoxon Signed Ranks test. For the Sick group, the mean after warm-up (SSQ2) was greater than before warm-up (SSQ1), $z = 2.36$, $p = .005$, and the mean after boxing (SSQ3) was greater than after warm-up (SSQ2), $z = 1.73$, $p = .037$. For the Well group, the mean after warm-up was greater than before warm-up, $z = 2.02$, $p = .04$, and the mean after boxing (SSQ3) was greater than after warm-up (SSQ2), $z = 2.82$, $p = .005$.

2.2. Cognitive performance

Following previous studies, in the Inspection task we took for granted that participants maintained their gaze within the boundaries of the blank target [16]. For the Search task, the dependent variable was the number of target letters reported. We conducted a 2 × 2 × 3 repeated measures ANOVA on factors Warm-up (Before warm-up vs. After warm-up), stance width (5 cm

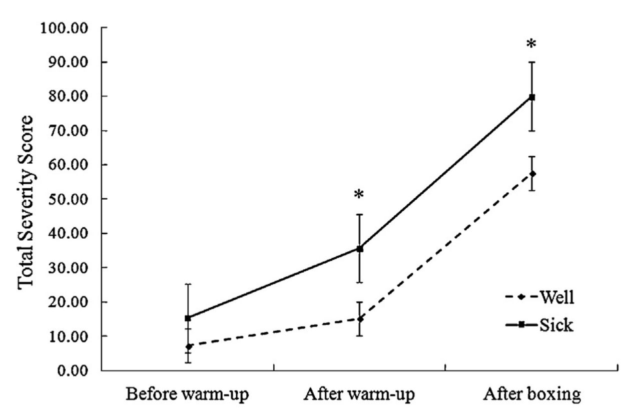

Fig. 1. Mean Total Severity Scores on the Simulator Sickness Questionnaire. The error bars illustrate standard error of the mean.