A preliminary cross-sectional assessment of postural control responses to continuous platform rotations following a sport-related concussion

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Abstract

Background: Individuals suffering a sport-related concussion typically recover within 1 month; however, persistent post-concussive symptoms are known to occur beyond this period. Clinical guidelines may not be sufficient to determine if dynamic postural control is still impaired at the point of the return to play decision.

Research Question: Do individuals with a previous sport-related concussion who have returned to play show differences in postural control compared to individuals without a previous concussion, in response to continuous platform perturbations?

Methods: Eight previously concussed and eight age- and position-matched participants completed six one-minute trials (three with eyes open/closed) whilst stood on a moving platform that rotated about the pitch axis with a peak-to-peak amplitude of 4° at a frequency of 0.8 Hz. Six trials were also captured during static quiet stance for comparison. Reactive and anticipatory stages of postural control were analysed by determining anteroposterior margins of stability (MoS) as a measure of whole-body postural control and head-to-trunk anchoring index as an indication of the head-trunk segmental coupling strategy.

Results: Posterior MoS during platform rotations reduced for both groups during eyes closed trials, but previously concussed participants exhibited a significantly greater reduction (1.97cm) in comparison to matched-controls (0.34cm). Participants, regardless of group, showed a preference towards a head-stabilised-to-trunk strategy during platform rotations. There were no differences during static trials.

Significance: This preliminary study suggests previously concussed athletes demonstrate a greater reduction in postural control whilst undergoing continuous platform rotations with eyes closed, which could indicate possible lingering deficits to other sensory systems such as the vestibular system, though participants were not likely to lose their balance.

Key Words: Sport Concussion, Margins of Stability, Anchoring Index, Return to Play, Postural Control

1.0 Introduction

Sport-related concussion (SRC) has been defined as a rapid onset of short-lived neurological impairment as a result of 'traumatic brain injury induced by biomechanical forces' [1]. Estimating SRC rates can be difficult due to inconsistencies in injury surveillance [2]. Nevertheless, previous estimates of 3.8 million SRCs occurring annually in the USA highlight the significance of the injury, with associated healthcare costs estimated to be $56 billion [3]. Awareness of, and an improved ability to screen for, SRC have resulted from an increased focus on education, in-game management, treatment of SRC and identifying dangerous head accelerations in recent years [2, 4-6]. Most individuals experiencing SRC recover from a clinical perspective within 1 month, with individual differences in recovery time; however, in some cases persistent post-concussive symptoms are known to occur beyond this period, delaying a clinical decision to return to play [7]. Present clinical guidelines may not be sufficient to determine if dynamic postural control is still impaired at the point of the return to play decision.

Return-to-play management of SRC is important for player safety: athletes should be free of SRC-related symptoms before returning to play. Recommended tools for assessing SRC are the Sport Concussion Assessment Tool 5th Edition (SCAT5) [8] and Child SCAT5 [9] which offer a standardised approach in assessing for injury [2]. These assessments aid diagnosis and take into account possible SRC symptoms related to postural control and sensory integration. Postural control is the ability to achieve, maintain or restore balance during any activity or posture by applying corrective torques to counteract those produced by gravity [10]. The three primary sensory systems responsible for maintaining postural control are the visual, vestibular, and proprioceptive sensory systems. These systems integrate sensory input to provide important information about spatial orientation within the environment, stabilise vision during rotational movements and linear accelerations of the head, and gauge the relative position and motion of neighbouring body parts to maintain postural control. Examples of impairments affecting how the sensory system operates following concussion include oculomotor dysfunction such as disconjugate eye movements [11], increased saccadic latencies [12], dizziness [13, 14], and impaired gait stability [15], though these findings are not exclusive to both children and adults. When these sensory systems are impaired because of SRC, the ability to maintain postural control is reduced [16]. Challenging one or more of the sensory systems could therefore be an essential for assessing postural control to ensure safe return to play following SRC.

Limitations with assessing and monitoring SRC symptoms include relying on subjective assessment of the athlete completing balance tasks that do not typically reflect the dynamic requirements and postural demands experienced within game situations. For example, the modified Balance Error Scoring System (mBESS), part of the SCAT5 assessment tool, evaluates postural control by asking the athlete to maintain balance with eyes closed during double, single and tandem stance. Assessments in static poses rarely form part of the requirements of game situations where SRC is likely to occur. Developing an assessment of dynamic postural control which does not rely on subjective assessment of the athlete completing a series of static balance tasks whilst also providing insights in to the neural control of balance is therefore more desirable.

Objective biomechanical measures that reflect the dynamic requirements of postural control in adults, such as the velocity of the centre of pressure (CoP) [17] and postural sway determined by inertial sensor based approaches [16], have previously been used to assess recovery from SRC. Athletes suffering SRC returned to typical values of CoP displacement following a return to play, but CoP velocity remained increased compared to matched controls when completing a standing balance task with eyes closed [17]. The authors suggest this may be due to an increased demand placed on the vestibular and proprioceptive sensory systems since they removed visual input during the task. Another measure of postural control is the margin of stability (MoS) which reflects the position of the extrapolated centre of mass (CoM) relative to the border of the base of support (BoS) [18] may be more appropriate in dynamic moving platform tasks. Stabilisation of the head, where the sensory organs of the visual and vestibular systems are located and known to be affected by an SRC, is also essential for maintaining postural control [19]. Understanding the interaction between the head and trunk unit during recovery from SRC could therefore be important and has not previously been determined. This can be achieved in one of two ways: the head can be stabilised to the inferior segment (the trunk) referred to as the head stabilised to trunk strategy (HSTS). To compensate for sensory impairment, individuals might adopt this strategy (i.e. lock the head to the trunk) in order to stabilise sensory inputs. Alternatively, the head can be stabilised within 3D space, referred to as the head stabilised in space strategy (HSSS) [20]. The Anchoring Index (AI) provides a measure of this stabilisation strategy [21]. HSSS is often preferred in low-difficulty tasks, while HSTS is often adopted as task difficulty increases [22].

This study aimed to determine postural control in young adults with a previous SRC who had returned to play, whilst being perturbed by a moving platform, compared to a matched control group. It was hypothesised that postural control would be impaired in individuals who had previously suffered SRC, demonstrated by a reduced MoS and adoption of a HSTS strategy during platform perturbations when vision was removed.

2.0 Methods

2.1 Participants

Eight previous SRC participants (average±1SD; age: 21.9±2.8 years, height: 1.8±0.7m, mass: 85.0±20.0kg, 3 females) and eight non-SRC participants (average±1SD; age: 21.5±1.2 years, height: 1.8±0.3m, mass: 79.2±7.9kg, 3 females) matched for age, sporting level and position took part in the study. A priori statistical power calculations (Gpower statistical software) using data from Powers et al [2014] estimated 4 participants per group were required to identify a meaningful difference in anteroposterior centre of pressure velocity between groups (mean difference = 6.17, $\sigma = 1.11$, $\alpha = 0.05$, power = 95%). All SRC participants suffered SRC within the last 6 months that required them to miss a fixture/match/game/training session in their chosen sport, or a day of higher education/work, but had since been cleared to return to play by their team medical practitioner/physician with no known symptoms remaining due to SRC. Individuals who had suffered a non-SRC, or diagnosed with a neurological or vestibular condition affecting balance performance were excluded. All participants provided written informed consent to take part, the tenets of the Declaration of Helsinki were observed and institutional ethical approval was obtained.

2.2 Protocol

Participants completed six one-minute unperturbed and perturbed standing trials with feet positioned shoulder-width apart, arms placed on hips with elbows turned outwards and head facing forwards. Six successive trials (3 eyes open (EO), 3 eyes closed (EC)) of unperturbed stance were followed by six (3 EO, 3 EC) perturbed trials. Presentation order of visual conditions was counterbalanced between matched pairs [17]. For perturbation trials, participants stood on a hydraulic movable platform (CAREN platform, Motekforce Link, Netherlands), ankles aligned with the surface axis of rotation. The platform perturbed participants by rotation about the pitch axis of the platform using a sinusoidal input function with a peak-to-peak amplitude of 4° (range -2° to +2°) at a frequency of 0.8Hz. Whole-body kinematics (excluding arms) were captured at 100Hz using a 16-camera motion capture system (Vicon, Oxford Metrics, UK).

2.3 Data Analysis

Marker trajectories were labelled and gap filled using Nexus 2.6 (Vicon, Oxford, UK), with further analysis in Visual 3D (C-Motion, Germantown, USA). All trajectories were smoothed using a 4th order Butterworth low-pass digital filter with a 6 Hz cut-off. For the platform rotation trials, two well-established periods of time were considered: (i) the first five cycles of platform rotation, defined as the reactive stage of postural control (to monitor initial adjustments/responses to perturbation) and (ii) the last eight cycles, defined as the anticipatory postural responses of the 'steady-state' stages (to assess adaptation over time) [22]. The MoS and the AI were determined for each stage. Unperturbed standing trials was analysed across the full one-minute time period.

2.3.1 Margins of Stability

Whole-body CoM was computed based on the segmental positions of the head, trunk, pelvis, thighs, shanks and feet. The sagittal plane margins of stability (MoS) were calculated as the minimum distance between the extrapolated centre of mass (*xCoM*) and boundaries of the base of support (BoS) [18];

$$MoS = BoS - xCoM \quad (\text{Eq. } 1)$$

Where *xCoM* was defined as;

$$xCoM = pCoM + vCoM/\sqrt{(gl^{-1})} \quad (\text{Eq. } 2)$$

where *pCoM* is the AP position of the CoM, *vCoM* is the instantaneous AP velocity of the CoM, *g* is acceleration due to gravity, and *l* is the absolute distance between the CoM and the ankle joint centre. BoS was defined as the midpoint between left and right toe markers in the anterior direction and midpoint between left and right calcaneal markers in the posterior direction. A lower value of MoS indicated the *xCoM* was closer to the border of the base of support. The minimum values of the anterior and posterior MoS during the one-minute unperturbed trials and the reactive/anticipatory stages of perturbation trials were extracted for further analysis.

2.3.2 Anchoring Index

The absolute pitch angle of the head compared to the external lab coordinate system and relative pitch angle of the head compared to the trunk were computed. These values were used to calculate the AI (equation 3) to determine the stabilisation strategy of the head segment [21]:

$$AI = [\sigma_r^2 - \sigma_a^2]/[\sigma_r^2 + \sigma_a^2] \qquad (\text{Eq. } 3)$$

where σ_a is the standard deviation of the absolute head angle relative to the external lab coordinate system, σ_r is the standard deviation of the head angle relative to the trunk segment. A positive AI represented a head stabilised in space strategy (HSSS), a negative AI represented a head stabilised on trunk strategy (HSTS).

2.4 Statistical Analysis

The averages of successive trials for each block of trials (condition) were considered for statistical analysis. Matching previous SRC and non-SRC participants for age, playing level and position allowed consideration of group as a repeated factor during statistical analysis. Therefore, a three-way repeated measures analysis of variance (ANOVA) (SPSS 24.0 for Windows, Chicago, IL, USA) determined differences during perturbation trials with time (reactive or anticipatory stage), group (previous SRC or non-SRC participants) and visual condition (EO or EC) as repeated factors. A two-way repeated measures ANOVA determined differences during the unperturbed trials with group (previous SRC or non-SRC participants) and visual condition (EO or EC) as repeated factors. Post-hoc analyses were performed using a Bonferroni correction and level of significance was set at $p<0.05$. Effect sizes are reported as both partial and generalised eta squared values [23, 24]. Unperturbed and perturbed trials were not compared.

3.0 Results

There were no significant interactions or main effects during unperturbed trials between groups or visual conditions (Table 1).

3.1 Margins of Stability

Anterior Margin of Stability

During perturbed trials there was a significant interaction between time and vision ($F_{1, 7}$=16.668, P=0.005, η_p^2=0.704, η_G^2=0.064). With EC, MoS decreased by 1.35cm from the reactive to anticipatory stage. There was a 0.17cm increase between the reactive and anticipatory stages with EO. A significant main effect for visual condition between EC (6.96±0.53cm) and EO (8.70±0.58cm) was present ($F_{1, 7}$=2.465, P<0.001, η_p^2=0.872, η_G^2=0.259) (Table 2).

Posterior Margin of Stability

There was a significant interaction between group and vision during perturbation trials; previous SRC participants' MoS decreased by 1.97cm during EC trials compared to EO, whilst control participants' MoS decreased by 0.34cm ($F_{1, 7}$=10.424, P=0.014, η_p^2=0.598, η_G^2=0.133) (figure 1).

There was also a significant interaction between time and vision ($F_{1, 7}$=14.705, P=0.006, η_p^2=0.678, η_G^2=0.178). With EC the MoS increased by 2.29cm from the reactive to anticipatory stage. With EO, there was an increase of 0.37cm in the anticipatory stage. There was a significant main effect of time, with MoS increasing by 1.33cm from the reactive to anticipatory stage, ($F_{1, 7}$=26.825, P=0.001, η_p^2=0.793, η_G^2=0.294). Vision had a significant main effect on posterior MoS, decreasing by 1.16cm during EC trials (EC=12.76±0.39cm, EO=13.93±0.48cm, $F_{1, 7}$=5.898, P=0.046, η_p^2=0.457, η_G^2=0.200).

TABLE 1
TABLE 2
FIGURE 1

3.2 Anchoring Index

Head-to-Trunk Anchoring Index

A significant interaction between time and vision was present during perturbation trials; during the reactive stage AI decreased by 0.29 with EC compared to EO, but during the anticipatory stage AI decreased by 0.07 with EC ($F_{1, 7}$=11.303, P=0.012, η_p^2=0.618, η_G^2=0.180) (figure 2). There was a significant main effect of time, with an AI of -0.12±0.25 during the reactive stage, compared to -0.31±0.21 in the anticipatory stage ($F_{1, 7}$=7.681, P=0.028, η_p^2=0.523, η_G^2=0.316). There was a significant main effect of vision; with EC, AI was -0.30±0.24 compared to -0.13±0.23 with EO ($F_{1, 7}$=115.208, P=0.000, η_p^2=0.943, η_G^2=0.383).

FIGURE 2

4.0 Discussion

The present study investigated whether athletes who had previously suffered SRC exhibited deficits in postural control, and the strategy used to achieve postural control, in response to platform rotations after they had returned to play. Results indicate partial support for our hypotheses. A group by vision interaction for posterior MoS was present during perturbation trials, with previously concussed individuals closer to the border of the base of support than matched controls. Irrespective of group, vision had a significant impact on postural control evidenced by a reduced MoS and increased preference for HSTS during perturbation trials. The lack of a main effect of vision during the standing trials indicates that removing vision during quiet stance was not sufficient to cause difficulty in maintaining postural control. However, care should be taken when generalising our findings due to limited knowledge regarding the period of time that had elapsed and number of sessions missed since participants had suffered their SRC. Factors that may influence recovery from SRC include period of rest, reintroduction to activity and exercise, physical and psychological therapy [2], therefore these factors could have influenced our findings. Furthermore, participants were recruited from the university/amateur sports teams, however individuals competing at professional/semi-professional level are likely to receive greater attention which could differentially influence recovery time.

Removing vision whilst challenging proprioception (platform perturbations) may have placed an increased demand on the way in which sensory inputs are weighted, and possible deficits in a SRC athlete's ability to process this information could be responsible [11-14, 17]. This potential sensory reweighting could have increased the demand on the vestibular or proprioceptive system and is a possible explanation for the shift towards HSTS during the reactive stage when vision was removed. The removal of vision in combination with initial exposure to platform movements are considered to increase task difficulty and as a result, the degrees of freedom are reduced [22, 25]. Locking of the head to the trunk is therefore a functional method of stiffening to provide a stable egocentric frame of reference [20]. This would suggest that postural control assessment in SRC management should not rely solely on quiet stance, rather should include a degree of dynamic control through perturbation in combination with the removal and/or addition of multiple sensory cues to challenge the sensory system. However, this hypothetical link, whilst logical, requires further investigation.

The hypothesis that previous SRC athletes would rely more on HSTS compared to the controls was unsupported. Instead, no differences in AI between groups during standing and perturbation trials indicates that previous SRC athletes had reverted to a similar stabilisation strategy as matched controls. Since athletes with a previous SRC are adaptable in their ability to adopt new strategies to produce functional movement and appear symptom-free [26], future research should continue to assess AI but focus on the symptomatic phase of SRC to establish whether changes in the head-trunk segmental control strategy are exhibited. An increasing posterior MoS in the anticipatory compared to the reactive stage suggests that postural control is improved as individuals (regardless of a previous SRC) adapt to the postural challenge. Considering there is an associated learning effect involved in the completion of the mBESS [27], and the present findings indicate a similar change in postural control over a one-minute period, future assessment of SRC may be better focused on the reactive stage only in perturbation trials, during which there is an initial increase in the postural task difficulty.

Participants used an unexpected HSTS in the anticipatory stage of perturbation trials. Since this stage was considered 'steady state' (i.e. a period of predictable platform movement), we expected participants to shift towards a HSSS (i.e. anticipatory postural control), as seen in previous research [22, 28]. A HSSS provides a stable allocentric frame of reference for the head, which is considered to be the more efficient strategy when dealing with an increased threat to equilibrium, such as removal of vision or destabilising platform rotations [29]. Sensory reweighting during, or leading up to, the steady state period may help to explain this preference towards HSTS. For example, Isableu et al. [30] suggested that a change in responsiveness could be a result of a shift in central set point (i.e. a shift in reliance on one source of information (e.g. visual) to another (e.g. vestibular or proprioceptive). However, this is unlikely in our case, as trials with full vision also demonstrated a shift to HSTS in the anticipatory stage. It is possible the perturbations were not destabilising enough to elicit an adequate change in AI from reactive to anticipatory measures.

Further investigation using similar methods from the present study may be necessary to determine how soon an athlete should return to play following SRC. Modifications to the perturbation trials, such as increases in the frequency or magnitude of the platform rotations, or a change in the direction or type of platform movement (e.g. translation rather than rotation) could elicit larger differences between groups and better inform the monitoring of athletes before returning to play. A more comprehensive approach to challenging the reactive and anticipatory responses of postural control might be to increase the frequency of perturbations at successive time intervals within trials [22], or to use pseudo-random stimuli that challenges sensory-motor control, such as the central sensorimotor integration test [31]. Since balance deficits in athletes with a previous SRC are also pronounced in the mediolateral direction [15], mediolateral platform perturbations could also be used in future to challenge multi-directional postural control. Future studies may also look to investigate movements similar to those produced during platform perturbations, such as consecutive heel-toe raises, which could provide clinicians with a simple method of assessing balance control without the need for more comprehensive equipment such as a moving platform.

4.1. Limitations

Small-scale studies with low participant numbers, if well designed and well executed, but preliminary in nature, can advance the scientific understanding of an important research field. Although low, the small sample size in this study may be used to inform sample size estimations for similar future studies on dynamic postural control in individuals with previous SRC, or might help to inform future meta-analyses investigating perceived worthwhile effects in response to dynamic task requirements [32]. Future research should ensure that individuals are monitored both in the symptomatic and asymptomatic phases of recovery, include responses to the SCAT5 at each of these phases, and take into account individual characteristics of the concussive incident to appreciate the immediate sensory impairments caused by the SRC. Based on these limitations, care should be taken when generalising our findings.

5.0 Conclusion

Athletes suffering SRC within the previous 6 months demonstrate a greater reduction in postural control in comparison to matched controls whilst undergoing perturbation trials with EC, suggesting possible lingering deficits in postural control. However, a loss of balance or a fall occurring was unlikely. While the present perturbation trials may not be destabilising enough to elicit a loss of balance, the large effect sizes in our results suggest this method may be useful in developing more sensitive SRC assessments in future.

Declaration of interest; none

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Table 1. Changes in postural control during static quiet standing (mean (1SD)), in previous sport-related concussion and matched-control participants during eyes closed and eyes open conditions.

	Concussed		**Control**	
	Eyes Closed	**Eyes Open**	**Eyes Closed**	**Eyes Open**
Ant. Min. MoS (cm)	8.73 (1.46)	9.81 (1.63)	9.37 (1.50)	9.88 (2.47)
Post. Min MoS (cm)	14.95 (0.94)	14.51 (1.60)	15.04 (1.53)	14.80 (2.15)
Head-Trunk AI	-0.13 (0.31)	-0.12 (0.29)	-0.10 (0.21)	-0.18 (0.17)

Table 2. Changes in postural control in response to continuous platform rotations (mean (1SD)) during the reactive and anticipatory stage, in previous sport-related concussion and matched-control participants during eyes closed and eyes open conditions.

	Reactive stage				Anticipatory stage			
	Concussed		Control		Concussed		Control	
	Eyes Closed	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed	Eyes Open	Eyes Closed	Eyes Open
Ant. Min. MoS (cm) [a, d]	7.45 (2.19)	7.97 (1.74)	7.83 (1.40)	9.24 (1.45)	6.16 (2.00)	8.17 (2.35)	6.40 (1.80)	9.40 (2.0)
Post. Min MoS (cm) [a, b, c, d]	11.07 (1.68)	14.13 (1.67)	12.18 (2.53)	13.35 (1.69)	13.76 (0.78)	14.64 (1.65)	14.10 (2.50)	13.60 (1.60)
Head-Trunk AI [a, c, d]	-0.23 (0.22)	-0.03 (0.24)	-0.29 (0.25)	0.08 (0.13)	-0.32 (0.22)	-0.25 (0.16)	-0.37 (0.29)	-0.31 (0.16)

[a] Interaction between time and vision

[b] Interaction between group and vision

[c] Main effect of time

[d] Main effect of vision

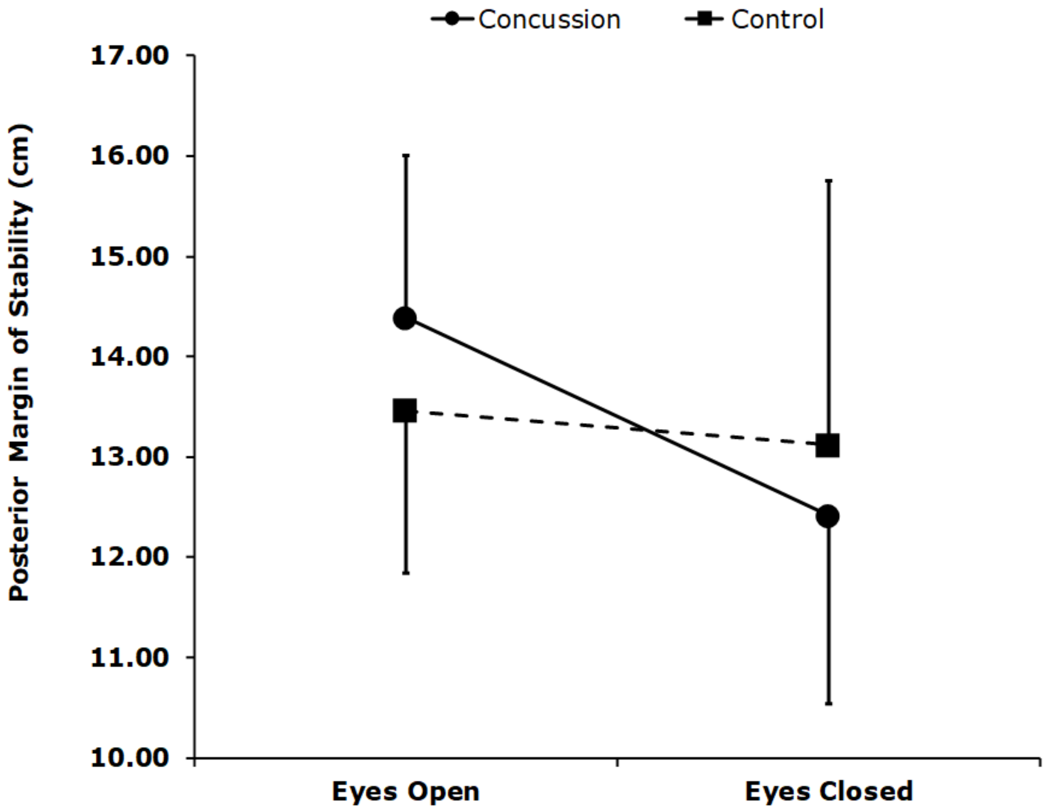

Figure 1. Posterior MoS (mean ± 1SD) during platform rotation trials was reduced for both groups of participants during eyes closed trials, but participants with a previous sport-related concussion exhibited a significantly greater reduction in comparison to matched-controls.

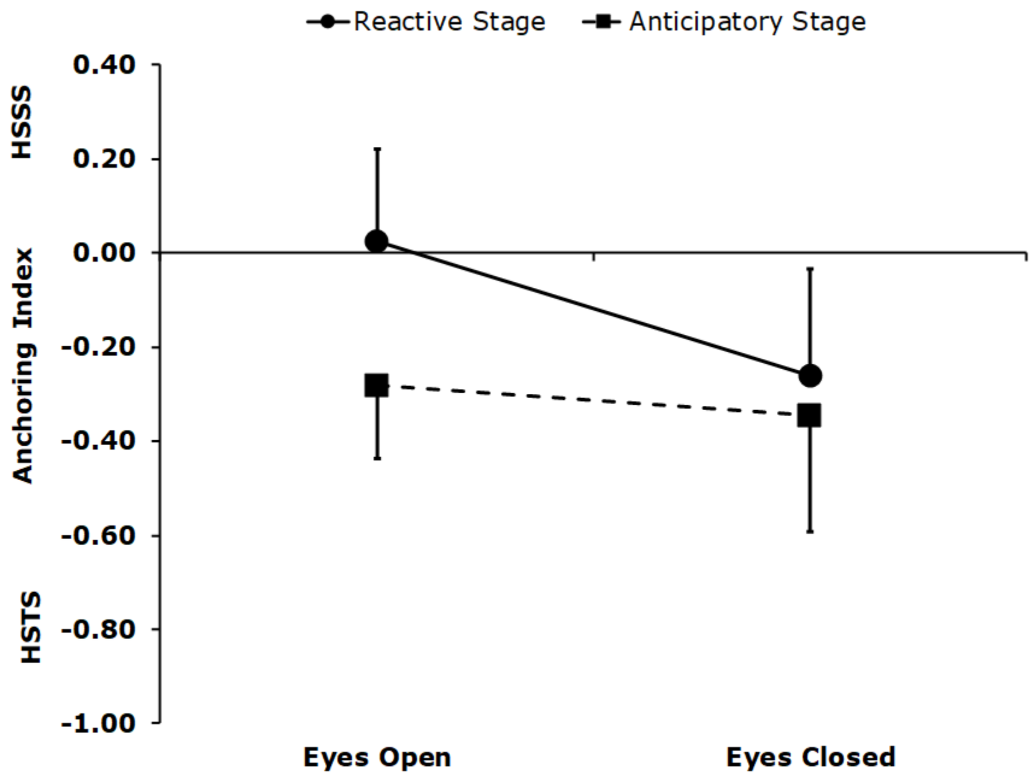

Figure 2. Anchoring index (mean ± 1SD) for previous sport-related concussion and matched controls combined during platform rotation trials. There was no strategy preference between the head and trunk during the reactive stage with eyes open, but a shift towards the head stabilised to trunk strategy when the eyes were closed. During the anticipatory stage participants chose the head stabilised to trunk strategy with eyes open or closed.