

Relationship between Information Processing and Postural Stability in Collegiate Division I NCAA Athletes: Does Concussion History Matter?

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Abstract

Background: Concussions have been associated with deficits in balance and postural stability. Subjects sustaining mild to moderate head injuries showed an increase in inhibition of the primary motor cortex which has been associated with sensorimotor organization and movement execution changes.

Purpose: The purpose of this study was to examine the relationship between postural stability and information processing in collegiate athletes with and without a history of concussion.

Methods: One-hundred and sixty-five Division I student-athletes completed balance and neurocognitive baseline testing. Thirty-four had a previous history of concussion. Postural sway and spatio-temporal characteristics of center of pressure were measured under four conditions: eyes open firm surface, eyes closed firm surface, eyes open foam surface, eyes closed foam surface. Information processing data came from two composite scores from a neurocognitive assessment tool and from a somatosensory stimulation test.

Results: Results showed that student-athletes with a history of concussions, although healthy at the time of testing, had differences in postural control compared to student-athletes without a history of concussion. While sway index scores were not significantly different, spatio-temporal measures showed larger displacements in CoP in previously concussed student-athletes. Reaction times and visual motor speeds were significantly correlated with sway index scores suggesting that processing time does influence balance control in all participants. Conclusion: Sustained balance control differences in previously concussed student-athletes may have implications for compensation strategies and risk of additional injuries.

Keywords: Balance; Neuropsychological testing; Reaction time; mTBI; Somatosensory

Introduction

Concussions, also known as mild traumatic brain injuries (mTBI), have nearly become an epidemic in the sports environment. Every year between 1.6 and 3.8 million athletes suffer from a concussion in the United States, and initial symptoms include headache, dizziness/balance deficits, and other cognitive impairments [1-5]. Returning an athlete prior to full recovery could result in further injury and consequently, recurrent concussions could lead to slowed neurological recovery [1,4]. However, detection of this injury commonly relies on the self reported symptoms of the athlete, yet over half of football concussions go unreported [6]. Therefore, it is important to understand what factors are affected following concussion, if they have any relationship, and if there are detrimental lingering deficits following a history of concussion.

Balance is considered an important variable in the identification and management of a concussion [7]. Balance deficits are a commonly reported symptom, but also show acute deficits following concussive injury [3,4,8,9]. Human upright stance is sustained by a postural control system that maintains the center of mass over the base of

support [10]. Balance is fundamentally a feedback system in the central nervous system (CNS) incorporating afferent sensory information from the somatosensory (proprioceptive), visual, and vestibular systems [7,8,10-12]. The organization of this sensory information results in a motor output. The role of the CNS in maintaining upright posture is divided into sensory organization and muscle coordination components [7]. Sensory organization includes timing, direction, and amplitude of movements and postural actions based on the information received from the sensory system [7]. Muscle coordination refers to the temporal sequencing and distribution of muscle contractions in the extremities and trunk that maintain balance [7]. Both of these processes work seamlessly together to maintain and control balance. Some balance assessments are able to challenge the CNS by perturbing one or more sensory inputs, visually with eyes closed, somatosensory with a foam surface, or vestibular with a visual-conflict dome or with eyes closed on a foam surface.

There is conflicting evidence as to which sensory system plays the largest role. Some indicate vision is of primary importance in stabilizing stance, therefore quick integration of visual input as well as adaptation to its absence is crucial in control of balance [13]. However, there is ample evidence that the vestibular system is important for functional balance mainly when there is a conflict between visual and proprioceptive input [14]. Improper integration of sensory

information as a result of a concussion may lead to balance difficulties and disorientation for an athlete. One assessment that uses a sophisticated force plate system and is also able to conflict both the visual and somatosensory is the Clinical Test of Sensory Interaction and Balance (CTSIB). Measures of balance such as amount of postural sway and center of pressure (CoP) can be collected using the CTSIB. Measurements utilizing force plate systems have previously identifying lingering deficits in balance that went unnoticed in common clinical measure such as the Balance Error Scoring System (BESS) [15-18]. This indicates that there may be lingering postural deficits in athletes who have returned to competition.

The primary motor cortex (M1), which is involved in executing motor movements, is inhibited following concussion [19]. There is also a strong association between mild to moderate head injuries and increased intracortical inhibition of M1; the greater number of previous concussions leads to greater M1 inhibition [19]. The primary motor cortex elicits its influence over lower extremity muscles involved in the management of balance through descending spinal tracts. Sport concussions may induce long lasting persistent deficits in the activity of the primary motor cortex, and in turn may influence postural sway and reaction time.

Reaction time is known as the time between the detection of a sensory stimulus and the motor response [20-22]. Reaction time is ultimately the time it takes to produce a motor output, and concussed individuals are substantially slower when performing a motor and cognitive task [23,24]. Concussed athletes have a significantly longer mean response time, indicating deficits in either the sensory integration or motor execution capabilities. Reaction time deficiencies are commonly associated with reduced dynamic balance control in concussed individuals [25]. Balance requires quick adjustments to minor postural disturbances; therefore, changes in motor processing time could affect balance and postural control in concussed athletes.

The purpose of the current study was to assess postural stability, reaction time, visual processing speed and the relation between these variables in athletes with a history of a concussion compared to those without a history. Three different reaction scores were collected; one was collected from a sensory component involving a response quickly after tactile stimulation to the index or middle finger. The other reaction scores were composite scores from the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) neurocognitive assessment, a reaction time composite and visual motor speed composite. The sensory response involves the somatosensory system, whereas the ImPACT composites are obtained through a level of cognitive and visuomotor processing. Understanding if a relationship exists between either of these reaction time scores and balance can help us understand and possibly explain underlying contributions to changes or deficits in balance. In addition, assessment of spatio-temporal characteristics of CoP will help us understand underlying mechanisms that may contribute to differences in stability. Overall, this research will help us understand how sensory processing and integration are related to balance as well as how concussive injuries may affect these processing systems.

Methods

Subjects

All subjects were a part of an ongoing investigation of a multitude of concussive effects on collegiate student-athletes. All participants

were volunteers for this study and signed the IRB forms. All subjects completed baseline evaluations and for the purpose of this study only data collected from the balance, ImPACT and sensory protocol was analyzed.

One hundred and sixty-five NCAA Division I athletes (116 male, 49 female: average 19.0 + 1.4 years old) completed the balance and ImPACT testing, 119 of them also completed the sensory portion. These subjects were split into two groups: previously concussed (25 males, 9 females), and no history of concussion (91 males, 40 females). Those with a history of concussion had all be released to return to play and the measures taken were considered baseline data. All subjects were varsity student-athletes tested during their collegiate careers. Sports included football (n=53), women's soccer (n=8), baseball (n=40), women's basketball (n=7), men's basketball (n=12), softball (n=20), men's soccer (n=11), and volleyball (n=14). See Table 1 for more demographics of our sample.

	N	# w/ previous concussion	Age (years)	Height (in)	Weight (lb)
Football	53	13	19.2 + 3.3	71.9+ 4.5	217.2+ 40.4
Men's Basketball	12	2	19.5+ 1.6	75.2+ 4.0	195.7+ 21.8
Women's Soccer	8	0	18.0+ 0.5	64.6+ 2.1	130.6+ 8.9
Men's Soccer	11	3	18.4+ 1.0	70.5+ 2.2	161.0+ 11.9
Women's Basketball	7	4	18.4+ 1.5	70.3+ 4.3	155.1+ 22.8
Volleyball	14	3	19.5+ 1.3	70.4+ 3.6	155.6+ 21.0
Softball	20	2	19.4+ 1.0	66.6+ 2.8	152.1+ 20.4
Baseball	40	7	19.8+ 1.3	72.5+ 2.4	192.3+ 18.4
Total	165	34	19.0+ 1.4	70.2+ 3.2	169.9+ 20.7

Table 1: Subject demographics.

Balance

All participants wore the same slip resistance socks while standing comfortably with feet shoulder width apart on the Biodex Balance System SDTM (Biodex Medical Systems, Inc., Shirley, NY). Participants became familiar with the platform and the task before recording was conducted. Initial demographic information was recorded (subject number, height, age). The modified Clinical Test of Sensory Interaction on Balance (mCTSIB) protocol was conducted which allows four different conditions: eyes open firm surface, eyes closed firm surface, eyes open foam surface, eyes closed foam surface. One trial of each condition was conducted for 20 seconds. Five seconds of rest was allowed in between each trial and approximately 30secs between each block condition. The Biodex Balance System allows data collection at 20Hz. A sway index calculated using the position of CoP was recorded under each condition, with a higher score indicating more sway.

In addition, several measures related to spatio-temporal characteristics of CoP were calculated using custom scripts written using MATLAB (MathWorks, Natick, MA). MedioLateral (ML) and AnteriorPosterior (AP) measures were calculated for Range; Path Length; Mean Velocity; and RMS Displacement. Total Path Length, Sway Area, and 95% Ellipse of Sway Area were also calculated.

Impact

All participants completed a baseline of the ImPACTTM concussion-management software (version 4.0; ImPACTTM Applications, Inc.; Pittsburgh, PA). This windows-based program is module-based and takes approximately 30 minutes to complete. First, demographic information as well as health history is collected. Next, the neuropsychological tests were performed, involving testing for attention span, working memory, recall, and response variability. The variables this study is interested in were the reaction time and visual motor speed composite score. Both of these are measurements of cognitive and visuomotor speed.

Sensory

Participants were seated at a computer with the left arm resting on a small portable tactile stimulator containing two stimulating probes in which the subject placed the forefinger and middle finger on top of the probes (CM-4, Cortical Metrics) [26]. Stimulus probes (roughly 5 mm flat tip) contacted the skin and provided a gentle (non-painful) stimulation. There are multiple tests that are performed over the course of 15-20 minute period. These include simple reaction time, a frequency discrimination, time interval discrimination, and amplitude discrimination. Each test lasted about 3-5 minutes with roughly 40-60 stimulus presentations. Only the simple reaction time scores were examined in this study.

Data Analysis

A 2 Vision (eyes open or closed) $\times$ 2 Surface (solid or foam) $\times$ 2 Concussion History (Yes or No) repeated measures MANOVA was performed on balance measures. T-tests between groups were conducted on the reaction time measures (sensory 1 & 2, ImPACT Reaction Time Composite and Visual Motor Speed Composite). A Pearson correlation was conducted across measures to look at the relationship between variables. Significance was set at $\alpha=0.05$ and trends were reported at $\alpha=0.1$.

Results

Balance scores

There was a significant Vision Effect ($F(1,150)=414.56$, $p<0.001$) with higher sway index scores in the no vision conditions. There was a significant Surface Effect ($F(1,150)=677.48$, $p<0.001$) with higher sway index scores in the foam conditions. There was not a significant Group Effect ($p>0.05$). There was a Surface $\times$ Group Trend ($F(1,150)=3.06$, $p=0.08$) and a Surface $\times$ Vision $\times$ Group Trend ($F(1,150)=2.941$, $p=0.09$), with the concussed group showing differential performance on the eyes open foam condition compared to the non-concussed. There were no other significant or trending interactions ($p>0.1$) (Figure 1).

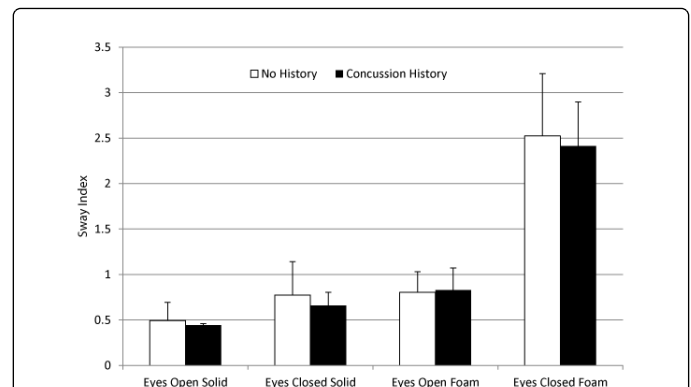


Figure 1: Mean (sd) of sway index scores showing the differences in body sway between previously concussed and non-concussed athletes on four different balance conditions.

CoP spatio-temporal measures

All spatio-temporal measures showed significant Vision, Surface, and Vision by Surface Interactions ($p<0.05$) (Table 2). Interestingly, there was a significant Group Effect for AP RMS Displacement ($p<0.05$) with Concussed group having larger displacement (Figure 2), and there were trends toward a Vision $\times$ Group and Surface $\times$ Group interaction ($p<0.10$) with Concussed group showing larger ranges in the ML direction in the absence of vision and on the foam surface (Figure 3).

	Vision Effect F(1, 157)	Surface Effect F(1, 157)	Group Effect F(1, 157)	Vision $\times$ Group F(1, 157)	Surface $\times$ Group F(1, 157)	Vision $\times$ Surface F(1, 157)
Sway Score	572.04, $p<0.001$	1045.01, $p<0.001$	NS	NS	NS	485.01, $p<0.001$
ML Range	403.46, $p<0.001$	615.81, $p<0.001$	NS	2.67, $p=0.08$	3.45, $p=0.06$	357.45, $p<0.001$
AP Range	534.65, $p<0.001$	523.24, $p<0.001$	NS	NS	NS	279.04, $p<0.001$
Sway Area	238.09, $p<0.001$	268.93, $p<0.001$	NS	NS	NS	218.02, $p<0.001$
ML Path Length	380.13, $p<0.001$	473.51, $p<0.001$	NS	NS	NS	307.96, $p<0.001$
AP Path Length	540.64, $p<0.001$	572.22, $p<0.001$	NS	NS	NS	338.48, $p<0.001$
Total Path Length	554.36, $p<0.001$	617.59, $p<0.001$	NS	NS	NS	373.61, $p<0.001$

ML Mean Velocity	380.13, p<0.001	473.51, p<0.001	NS	NS	NS	307.96, p<0.001
AP Mean Velocity	540.64, p<0.001	572.33, p<0.001	NS	NS	NS	338.48, p<0.001
ML RMS Displacement	439.83, p<0.001	690.92, p<0.001	NS	NS	NS	397.09, p<0.001
AP RMS Displacement	594.67, p<0.001	575.73, p<0.001	4.40, p<0.05	NS	3.29, p=0.07	300.79, p<0.001
Ellipse 95% Sway Area	245.28, p<0.001	284.09, p<0.001	NS	NS	NS	227.38, p<0.001

Table 2: F-scores and p-values for all CoP Spatio-Temporal Measures.

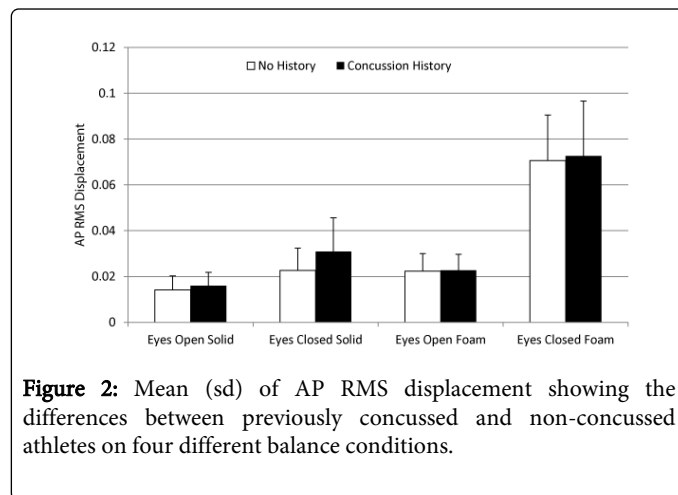


Figure 2: Mean (sd) of AP RMS displacement showing the differences between previously concussed and non-concussed athletes on four different balance conditions.

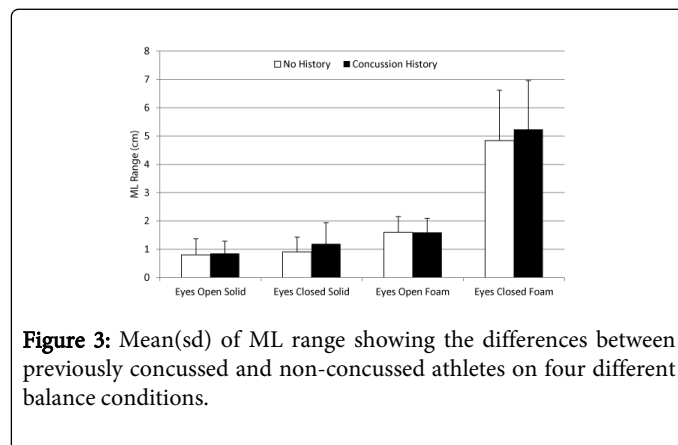


Figure 3: Mean(sd) of ML range showing the differences between previously concussed and non-concussed athletes on four different balance conditions.

Reaction time/impact

Comparisons between concussed and non-concussed groups were conducted for reaction time measures and visual motor speed. There were no significant differences between groups ($p>0.05$).

Pearson correlation analysis was conducted for sway measures across balance conditions, two trials of simple somatosensory reaction time and the ImPACT reaction time and visual motor speed

composites. Simple sensory reaction time trials 1 and 2 were significantly correlated with the ImPACT reaction time composite score ($r=0.270$, $p<0.01$ and $r=0.238$, $p<0.01$). There were also significant correlations between sway index scores in eyes closed firm, eyes open foam, and eyes closed foam conditions and ImPACT reaction time composite ($r=0.175$, $p<0.05$; $r=0.206$, $p<0.01$; $r=0.198$, $p<0.05$), respectively. The ImPACT visual motor composite was correlated with two balance conditions: eyes closed firm ($r=-0.265$, $p<0.001$) and eyes open foam ($r=-0.219$, $p=0.005$). While these correlations are significant, they are weak likely because of the differences in the tests. See Table 3 for correlations.

	ImPACT Reaction Time Composite	ImPACT Visual Motor Composite
Eyes Open Firm Surface (SI)	0.128 (0.101)	-0.009 (0.909)
Eyes Closed Firm Surface (SI)	0.175 (0.024)*	-0.265 (0.001)*
Eyes Open Foam Surface (SI)	0.206 (0.008)*	-0.219 (0.005)*
Eyes Closed Foam Surface (SI)	0.198 (0.011)*	-0.093 (0.237)

Table 3: Correlations between Sway Index Scores (SI) on balance conditions and ImPACT Reaction Time Composite and Visual Motor Speed Composite. R-values are reported first, then P values in parentheses. An asterisk indicates significance.

Discussion

Amount and postural sway is a behavioral measure of how sensory information is gathered, processed and integrated into a motor response. Understanding responses on postural manipulation, visual motor processing speed (ImPACT composite) and reaction time measures (simple sensory and ImPACT composite) can help in understanding if there are long-term differences in how information is processed. This may have implications in sport and daily life for athletes who have endured a concussion. Postural stability and reaction time require a level of information processing involving different sensory systems and cognitive systems.

Results showed that changing surface and thus saliency of somatosensory information, and removing vision led to higher sway index scores across all groups. Guskiewicz [7] noted that communication lost between the three sensory information systems would cause moderate to severe postural instability. Hence, higher sway index scores were observed when a sensory system was lost or distorted across all groups. No significant differences between the concussed and non-concussed existed, but this may be due to the sensitivity of our measures. There was a Surface $\times$ Group trend and a Surface $\times$ Vision $\times$ Group trend indicating that the concussed group was affected by surface and vision changes differently than the non-concussed group. This may reveal that the concussed group has greater difficulty when presented with conflicting sensory information. As mentioned earlier, individuals who have difficulty integrating sensory systems, as well as choosing the correct cues are going to have greater instability that is harder to overcome. Possibly, previously concussed athletes have particular difficulty when presented with vision information and distorted somatosensory information, and are unsure which to prioritize and use [7].

The difference between the concussed and non-concussed groups and how each group was affected based on the sensory information

received is shown in Figure 1. The concussed group had lower sway index scores than the non-concussed group in three out of the four conditions, although not significantly lower. This may seem as though this group is performing better than the non-concussed group. However, caution should be used in determining lower scores as better performance. When we examined the spatio-temporal characteristics of CoP, the groups are different on AP RMS Displacement and ML Range depending on conditions. The previously concussed group has a larger Displacement in the AP direction and more range in the ML condition suggesting that they deviated from center more than those without a history of concussion although maintaining a more stable position overall. It is possible that the formerly concussed group may have a processing strategy that causes co-contraction or a greater level of rigidity that is not seen in the athletes with no history of a concussion. The sway and spatio-temporal measures support this. A more rigid posture with larger deviations when disturbed can pose risks for injury if balance is disturbed.

Previous research has found CoP displacements to be less random and more regular in concussed athletes, this could potentially support a strategy created by this group [15,19]. Cavanaugh and colleagues suggest that the CoP oscillations may be due to abnormal changes in cortical oscillatory activity. The only condition in which the concussed group had a higher sway score was in the eyes open foam surface. Integrating visual information as well as distorted somatosensory information may be what is most difficult for the concussed group. Guskiewicz, et al. [2] suggest that the postural deficits are linked to sensory interaction problem, and concussed individuals may have difficulty choosing the correct postural cues. Lingering effects may cause this group to have difficulty integrating and processing different sensory information.

Further analysis should include assessment of the underlying pattern of control. General CoP measures are not sensitive to oscillations or variability within the balance measurements and may not be able to detect underlying deficits. Approximate entropy (ApEn) may be able to uncover variability and oscillations within individual measures [15,19]. ApEn and virtual time-to-contact measures may be able to detect postural abnormalities that are not observed during traditional balance testing up to a month following injury [27]. Residual postural abnormalities in concussed individuals may go undetected using conventional measures and injured athletes may be returning to competition before fully recovered. Unconventional measures could potentially portray more variability in the concussed group even though the groups were not significantly different. Also, it may help us understand that a lower sway score may not indicate better balance.

It is important to understand that the athletes in the “concussed” group are athletes that completed the baseline evaluation and are healthy and cleared to play but have in the past had at least one or more concussions. These recovered individuals may be processing information differently based on our results. If an athlete has difficulty processing sensory information; balance and reaction time will be greatly affected. Difficulties in balance and reaction time can be detrimental to an athlete’s success on the field or court as well as making one more susceptible to further injury.

Results showed significant correlations between the simple somatosensory reaction time and the ImPACT reaction time composite. The reaction time composite is a robust measure that likely involves a greater degree of cognitive processing compared to the simple somatosensory reaction results examined in this study. These

variables are correlated to each other as well as to majority of the balance scores. Broglio and colleagues (2009) found deficits in cognitive processing between the time of a stimulus and a response in athletes who had suffered a concussion within three years prior to the investigation. The significant correlation between balance and reaction time was hypothesized and leads us to believe that deficits in balance will also indicate deficits in reaction time, and this may be due to distorted information processing. Catena and colleagues (2011) discovered similar findings and observed changes in gait were related to slower reaction times in the Stroop task.

Interestingly, the visual motor speed was negatively correlated with sway index scores for the four balance conditions. Two of these values were significant (eyes closed firm surface, and eyes open foam surface). As the concussed group had lower, yet insignificant, sway index scores when compared to the non-concussed across four conditions they also had a higher visual motor speed, which is a measure of visuomotor processing. Even though there is no Group Effect, it provides a thought for further research in the visuomotor processing speed in relation to residual balance effects. Also, it may suggest that those with deficits in sensorimotor processing and integration may choose a strategy that involves co-contraction or more rigidity to maintain stability. This could negatively affect performance in athletes as well as make them more susceptible to injury.

This research continues to promote a multifaceted approach to the management and evaluation of concussive injuries. The results suggest that there may be lingering deficits in individuals who have suffered a concussion. As far as balance, it is important to evaluate balance as an absolute measure since lower sway index scores are debatable in whether or not they convey better balance. A complete battery including a neurocognitive assessment and a balance assessment with variability measures may be useful and most effective in identifying residual effects as well as managing the road to recovery.

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