The Relationship of Visuo-Motor Processing and Upright Balance in Acutely Concussed Athletes

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Abstract

Context: Following a concussion, athletes display impairments in upright balance, as well as changes in visual acuity. Balance deficits arise as a result of sensory information integration impartments when sensory information processing is delayed or altered. Investigating the relationship between visual processing and balance following a concussion will help to better understand the underlying pathophysiologic mechanisms for balance deficits and why altered visuo-motor processing may be related to postural instability.

Objective: To establish the relationship between visuo-motor processing and upright balance.

Design: Longitudinal cohort study.

Setting: University Research Laboratory.

Participants: 7 concussed [age (17.1±3.0 years), height (174.0±74. 2 cm), weight (73.3±23.8 kg)] and 7 matched control [age (17.3±3.1 years), height (178.8±11.6 cm), weight (77.9±23.4 kg)] subjects participated.

Intervention: Subjects completed the Simple Visuo-Motor Processing (SVMP) task, the Sensory Organization Test (SOT) and twice (within 48 hours after concussion and 10 days after concussion).

Main Outcome Measures: Descriptive statistics were calculated for each test battery. Pearson correlations were conducted between SVMP and SOT outcomes. Repeated measures ANOVA were also calculated to determine differences between day and between groups. Alpha level was set a priori at 0.10.

Conclusion: A relationship may exists between SVMP reaction time and balance, suggesting that while the tests may be evaluating different underlying independent constructs, both measures revealed specific deficits among concussed athletes. Athletic Trainers should consider visuo-motor testing as part of the battery of tests following a concussion.

Keywords: Visuo-Motor Processing; Concussion, Balance

Introduction

Sport-related concussion diagnosis and management pose a great challenge to health care providers. Concussion is not a structural injury that can routinely be noted on standard neuroimaging techniques such as computed tomography (CT) or magnetic resonance imaging (MRI) [1], as such, health care professionals must rely on subjective and other objective assessment tools to make the initial diagnosis and return to play decision.

Commonly administered tools used by athletic trainers following a concussion include self-reported symptom inventories, neuropsychological assessments, and balance assessments. Self-reported symptom inventories and neuropsychological assessments both have limitations related to their validity and reliability, even though they are used extensively [2]. The final component of the battery of testing for suspected concussions includes balance assessments. Researchers have identified alterations in balance following sport-related concussion [3-5] and have observed that these deficits typically resolve between 3 to 10 days after the injury [6-8].

Impairments in balance following a concussion have been related to either 1. A failure of sensory (visual, vestibular, somatosensory) information to properly integrate together [9], or 2. An individual relying too heavily on one of the individual systems to compensate for another sensory system that may be impaired [6]. The primary objective of balance assessments following a concussion is to identifying alterations within the three primary sensory systems that may be contributing to the balance impairments.

Balance measures such as the Sensory Organization Test (SOT), [7,8,10] is a high-technology computerized dynamic posturography (CDP) measure which has been used extensively to identify post-concussion balance deficits [4,11-13] and is a clinical test designed to systematically disrupt the sensory selection process by altering the information available to the somatosensory, vestibular and/ or visual systems [6]. The SOT was developed to isolate which sensory system is most involved in regulating balance and to determine how the interactions between these systems affects postural control [14]. The SOT is a valid test of balance impairments among athletes with mild traumatic brain injury (TBI) [9,10].

Balance deficits arise as result sensory information integration impairments [9] when sensory information processing is delayed. Information from the sensory systems may be delayed following a concussion as a result of the physiological changes that occur within the brain. Both a neurometabolic cascade [15] and diffuse axonal injuries [16] are believed to occur following a concussion and these may help to partially explain why information processing is delayed. The physiological changes that occur following a concussion take place at both a focal and wide-spread level, and can occur at the level of the brainstem up to the cortex [15]. This widespread damage may lead to impairments in information transmission via the axons. Stemming from the delayed information processing are possible impairments in balance as a result of a failure integrating of sensory information (vestibular, visual, and somatosensory). Impairments in any of the three sensory systems could lead to impaired balance; however the true extent of this relationship is not currently well understood. As the visual system contributes to balance by transmitting information about the external environment to determine where the body is in space, any impairment in the visual system may lead to symptoms of impaired balance (e.g. disequilibrium or imbalance). In addition to balance impairments attributable to visual system dysfunction, other visual symptoms (such as double vision, blurred vision, or sensitivity to light) may be experienced by the athlete following concussion [17].

Determining the relationship between visual impairments and impairments in balance following a concussive injury could allow clinicians to conduct a more thorough assessment of vision and balance and could potentially identify if a visual training protocol should be established. Simple visual processing testing protocols [17] can help identify deficits in visual processing and visual performance but have not been investigated among concussed athletes. Testing protocols that consist of first-order (i.e. simple or linear) [17] stimuli are defined by the luminance and color of the stimuli, and second-order (i.e. complex, non-linear) stimuli are defined by their contrast, texture and depth [18]. Optical flow refers to complex motion information representing the body moving through the environment [19,20]. Athletes must use all these stimuli (simple/linear, complex/non-linear, and optical flow) to generate an image of their surroundings and allow them to properly navigate through the environment without difficulty. Current approaches to concussion assessment do not address visual processing deficits directly, but rely on the resolution of self-reported visual (and other somatic, cognitive, and behavioral) symptoms to determine if recovery has occurred. Researchers have identified delayed perceptual deficits during complex visual tasks despite normal neurological examination findings and resolution of self-reported symptoms in children after a concussion [17]. Deficits in visual processing have been demonstrated in children ages 8 to 16 years during first- and second- order stimuli testing following a concussion [17]. There is no published research on how these processes are affected following a concussion in an older (ages 16 to 24 years) athletic population. The investigation of visual processing deficits and the relationship that these deficits have on upright balance in athletes will help to better understand the underlying pathophysiologic mechanisms for balance deficits and why altered visuo-motor processing may be related to postural instability typically seen following a concussion. The purpose of this study was to analyze the relationship between visuo-motor processing and upright postural stability in acutely concussed athletes through a simple visuo-motor processing task and computerized dynamic posturography.

Methods

Design

A longitudinal, matched cohort study design was used to assess the correlation between scores on a visuo-motor processing task with scores on standardized balance assessments. The independent variables included time (with 2 levels: day 1 and day 10) and group (with 2 levels: concussed and control subjects). The dependent variables included: (a) reaction time on a visuo-motor processing task, and (b) composite equilibrium score and sensory analysis on the SOT.

Subjects

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Seven acutely concussed subjects [age (17.1 ± 3.0 years), height (174.0 ± 74. 2 cm), and weight (73.3 ± 23.8 kg)] participated in the study. Subjects were included in the concussed group if they participated in an intercollegiate, interscholastic, or club sports and had been diagnosed with a concussion by a certified athletic trainer or physician trained sustained within the previous 48 hours. Concussion was defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces common features of a concussion include:(1) an injury caused by a direct blow to the head, face, neck, or elsewhere on the body with an 'impulsive' force transmitted to the head, (2) a concussion typically results in rapid onset of short-lived impairment of neurological function that resolves spontaneously, (3) the injury may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury, (4) a concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness, and (5) resolution of clinical and cognitive symptoms typically follows a sequential course [21]. Seven control subjects [age (17.3 ± 3.1 years), height (178.8 ± 11.6 cm), and weight (77.9 ± 23.4 kg)] matched according to age, sport, and gender also participated. All subjects were volunteers who signed a written informed consent or assent form. Human subject's approval was obtained from the Institutional Review Board prior to beginning the study.

Control subjects had no self-reported history of a concussion within the previous year. Additional exclusion criteria for subjects included any medications that may affect balance (e.g. non-steroidal anti-inflammatories, antidepressants, anticonvulsants, vestibular suppressants, neurostimulants, antimetics) taken within 2 hours of the scheduled testing, and lower extremity injury that may impair balance (e.g. ankle sprain), a previous concussion within the previous year, or vision less than 20/20 (corrected or uncorrected) as measured during the static visual acuity testing using the NeuroCom® InVision program (see Testing Procedures below).

Instrumentation

E-prime V1.2 software (Psychology Software, Pittsburgh PA), and a Dell laptop computer with an external keyboard were used for the visual processing task. To limit the number of errors from subjects using incorrect keys, a modified keyboard was used, in which all of the keys except the keys required for responses ('a', 'l', and 'spacebar') were removed. Visual acuity testing was conducted with the NeuroCom® InVision software (NeuroCom® International, Inc.; Clackamas, OR). The hardware for the visual acuity testing included a head- mounted tracking device that determines angle, distance, and velocity of head motion.

The NeuroCom SMART Balance System was be used for all balance assessments. Subjects were tested using pre-established standard NeuroCom protocol for the SOT [22].

Procedures

Subjects reported to the Laboratory on two separate occasions: within 48 hours and 10 days following injury. These testing time points were chosen based upon previous published research demonstrating initial deficits in postural stability and recovery comparable to control subjects within 1-10 days following a concussion [8,12]. Control subjects were assessed at the same time intervals but not necessarily on the same day as their matched concussed subjects. All subjects were screened using a self-reported medical screening for their eligibility to participate in the research study. Demographic information (i.e. height, weight, age, handedness, gender, and sport) was collected using standard techniques and entered into the E-prime and NeuroCom software data files.
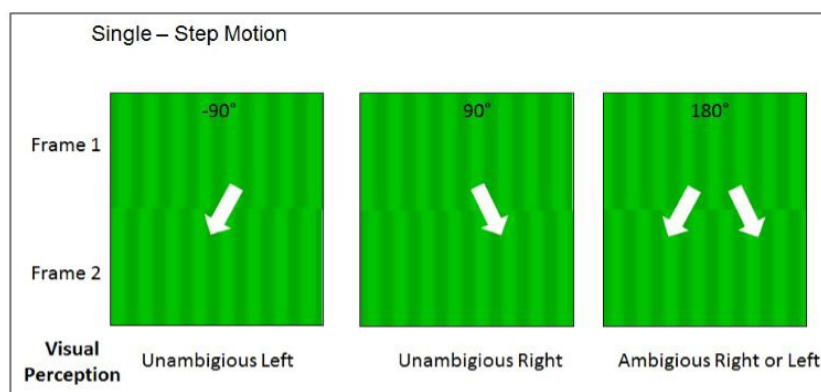

Figure 1: Visual stimuli for single motion sine wave gratings

All subjects underwent testing in a counter-balanced order for test (SOT and day (24-48 hours, 10 days)). Subjects were barefoot for all of the balance testing procedures and each subject's stance position was standardized according to the NeuroCom® protocol based upon their own height. All subjects were fitted with a safety harness prior to the start of the SOT and secured to the overhead frame to ensure their safety during testing. The SOT test protocol consists of 18 total trials (20 seconds per each trial) in each of 6 conditions. Subjects were presented with three different visual conditions (eyes closed, eyes open, and sway referenced surround), and two different somatosensory conditions (fixed and sway referenced) comprising the 6 different testing conditions. 'Sway-referencing' refers to the tilting of the support surface (i.e. force platform) or visual surround, or both. During each of the testing conditions, subjects were asked to stand as motionless as possible. Figure 1 depicts each of the 6 SOT conditions. Outcome measures from the SOT included: a composite equilibrium score, and sensory analysis ratio (visual, vestibular, somatosensory, and preference ratios). These scores are calculated using the NeuroCom® software and are automatically generated at the completion of the testing.

For the visual processing task subjects were seated at a distance of 24 inches from the computer screen with a modified keyboard on a desk in front of the subject. Subjects were shown a series of sine-wave gratings on a computer monitor with a refresh rate of 75 Hz and a screen resolution of 1024 X 768 pixels. Mean luminance for the stimuli was 14cd/m2. Figure 2 represents the 'motion jumps' subjects were tasked with identifying. During the task, subjects were asked to identify the direction (right or left) of each 'motion jump' and respond by pressing the corresponding key on the key board ('a' for left, 'l' for right).
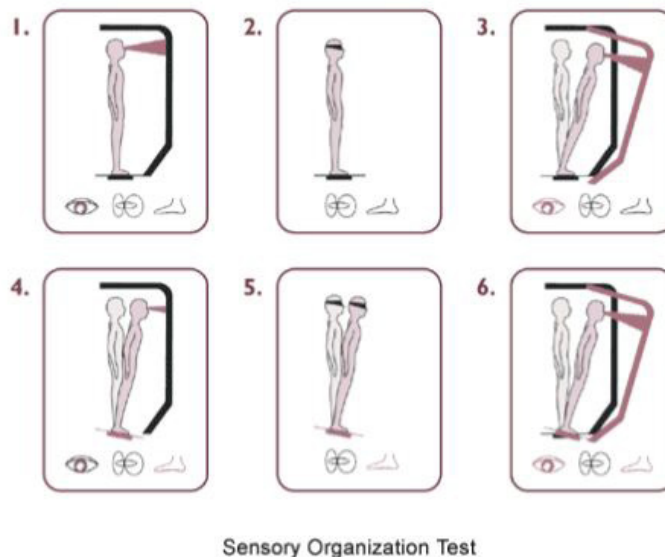
Figure 2: The Sensory Organization Test (SOT) six sensory conditions used with permission from Natus International

Each trial of the visual processing task began with a neutral stimuli (0°) followed by a second frame presented in one of three orientations: +90°, -90°, and 180°. Orientations of +90° and -90° were ambiguous right or ambiguous left motion while motion in the 180° was an unambiguous stimulus with no correct response. Right and left motion shifts are associated with +90° and -90° stimulus respectively, while 180° motion shifts represent a counter-phase shift with no correct response. Unambiguous trials were included to help determine if visual processing at higher levels of the brain are affected. Subjects completed 120 trials (40 trials in each orientation) in a random order as determined by E-prime software. The stimuli were constructed as in the 2D motion priming experiments reported by Pinkus and Pantle (1997) [23]. A 5-second inter-trial interval was used to diminish the effects of motion priming [influence of a previously perceived moving object on the subsequent perception of the motion of another moving object] [24] occurring between each trial.

Statistical Analysis

Subjects were instructed to look at the whole screen ("look globally") and not to focus on one individual place on the screen. Subjects were instructed to respond to each motion jump as quickly and accurately as possible. If the motion is in the left directions subjects are to press the 'a' button on the keyboard and if motion jump is to the right, subjects are to press the 'l' button in the keyboard. If a subject failed to respond within 5-seconds of the motion jump, the trial was marked as non-response and the next trial began automatically. If subjects were unsure of which direction the motion occurred, they will be instructed to press both the 'l' and 'a' buttons together. Testing lasted approximately 5 minutes and ended automatically after the completion of the all 120 trials. Data derived from this test included: reaction time, reaction time for 20 trials, and reaction time left/right/ambiguous. All data was extracted for analysis into an excel spreadsheet by the software at the conclusion of the session.

Descriptive statistics, measures of central tendency and variability were calculated to summarize the demographic characteristics of the sample. Separate repeated measure ANOVAs (with a bonferroni correction to account for the family wise error rate) were used for within-subject comparisons of scores of the SVMP (reaction time), and SOT (composite equilibrium score, sensory analysis) for each of the days of testing (day 1 and day 10). The between-subject factor was group (concussed and control). Post-hoc analyses were conducted for any significant interaction effects among the independent variables 'group,' 'condition,' or 'day.'

Bivariate correlations (Pearson product moment correlation (r) coefficients were conducted to determine the relationship between simple visuo-motor processing and balance in concussed and control subjects. All statistical analyses were performed with SPSS software (PASW Statistics version 18.0, SPSS Inc., Chicago, IL). An a priori alpha level of $P<.10$ was applied to all data to determine significant differences. An alpha level of $p<.10$ was chosen because the research question was exploratory in nature and the testing procedures (i.e. visual processing task) have not been used previously in the selected population or with the same outcomes.

Results

Descriptive statistics for the SVMP task and SOT are presented in Table 1. Pearson correlations revealed significant correlations for a number of outcomes in both groups (concussed and control) and for both days (day 1 and day 10) which are presented in Table 2. SVMP variables not included in the table did not show significant correlations for either group or day when compared with SOT outcomes.

Test	Variable	Concussed (n=7)		Control (n=7)	
		Day 1	Day 10	Day 1	Day 10
SVMP	Overall Reaction Time[a]	496.18±52.85*	439.01±20.62*	436.32±74.37	433.14±66.60
	Reaction Time Trials 1-20[a]	500.13±74.85	431.67±62.80	445.72±122.08	438.02±37.11
	Reaction Time Trials 21-40[a]	451.05±73.82	437.63±34.82	432.13±96.70	430.19±87.48
	Reaction Time Trials 41-60[a]	466.92±58.61	427.02±36.87	451.54±68.30	422.10±81.32
	Reaction Time Trials 61-80[a]	530.24±147.81	431.30±17.82	434.06±70.05	436.24±89.89
	Reaction Time Trials 81-100[a]	532.31±107.37*†	421.00±25.92*	422.35±80.04†	424.70±56.97
	Reaction Time Trials 101-120[a]	500.12±54.17†	484.77±43.10†	439.81±59.05†	427.76±68.77†
	Reaction Time Left[a]	484.97±64.60*	429.35±34.19*	448.98±91.32	431.15±71.51
	Reaction Time Right[a]	474.88±44.44*	413.76±28.79*	421.55±68.88	413.71±51.90
	Reaction Time Ambiguous[a]	530.22±62.74*†	472.30±26.98*	452.58±81.13†	448.89±77.21
SOT	Composite Equilibrium Score	73.14±5.73*	83.57±2.15*	78.71±7.74	82.00±5.39
	Somatosensory Ratio	1.09±0.07*†	1.03±0.04*	1.00±0.00†	1.04±0.05
	Visual Ratio	0.88±0.10*	0.97±0.03*†	0.88±0.10	0.93±0.04†
	Vestibular Ratio	0.61±0.09*†	0.80±0.05*	0.71±0.12†	0.77±0.09
	Preference	1.00±0.11	1.01±0.05	0.97±0.12	1.01±0.08

[a]Reaction Time measures in ms
*$p<0.10$; significant difference between days of testing
†$p<0.10$; significant differences between groups (concussed & control)
Table 1: Descriptive Statistics for SVMP, & SOT variables by Day and Group (mean ± SD)

				Pearson Correlation	Sig
Day 1	Concussed Control	SOT CES	SVMP Trials 101-120	-0.830	0.021
		SOT CES	SVMP Trials 1-20	-0.729	0.063
			SVMP RT Left	-0.677	0.095
		SOT PREF	SVMP RT Left	-0.683	0.091
Day 10	Concussed	SOT CES	SVMP Overall RT	-0.741	0.057
		SOT VEST	SVMP Trials 41-60	-0.762	0.047
			SVMP RT Right	-0.696	0.082
		SOT SOM	SVMP RT Right	0.673	0.098
		SOT PREF	SVMP Trials 41-60	-0.729	0.063
			SVMP RT Amb	-0.910	0.004

SOT: Sensory Organization Test, CES: Composite Equilibrium Score, SOM: Somatosensory Ratio, PREF: Preference Ratio, VEST: Vestibular Ration, Mean COG Sway Velocity, SVMP: Simple visuo-motor processing task, Amb: Ambiguous
Table 2: Significant Correlation between CDP and SVMP Task

Simple Visuo-Motor Processing Task

Separate two-way ANOVAs with repeated measures on the factor 'time' revealed a significant day by group interaction for: overall reaction time ($F_{1,6}$=3.780, =0.760, p=0.076, ω^2=0.240, 1-β=0.575), and reaction time for trials 81-100 ($F_{1,6}$= 5.475, Wilk's λ=0.687 , p=0.037, ω^2=0.251, 1-β=0.712). Independent pairwise post-hoc analysis revealed significant differences in the concussed group between day 1 and day 10. Overall reaction time on the SVMP task was significantly faster on day 10 in the concussed group (496.18 ± 52.85ms) compared to the control group (439.01 ± 20.62 ms, p=0.039) and reaction time on trials 81-100 was significantly faster on day 10 (concussed = 532.31 ± 107.37ms, control = 421.00 ± 25.92ms, p=0.017). Finally, on day 1of testing reaction time on trials 81-100 concussed subjects were significant slower than control subjects (532.31 ± 107.37ms, 422.35 ± 80.04ms, p=0.051). No other significant interactions were observed for the remaining SVMP variables.

Significant main effects on the variable 'day' were observed among concussed athletes for; SVMP reaction time left (concussed = 484.97 ± 64.60 ms, control = 429.35 ± 34.19 ms, p=0.031), SVMP reaction time right (concussed = 474.88 ± 44.44 ms, control = 413.76 ± 28.79 ms, p=0.040), and SVMP reaction time ambiguous trials (concussed = 530.22 ± 62.74 ms, control = 472.30 ± 226.98 ms, p=0.034). On day 1 of testing, a significant main effected was observed between the groups for reaction time on the ambiguous trails (concussed = 530.22 ± 62.74, control = 452.58 ± 81.13, p= 0.068). Concussed subjects were significantly slower than control subjects. No other significant main effects were noted for the remaining SVMP variables.

Computerized Dynamic Posturography Measures

Analysis on the composite equilibrium score (CES) data from the SOT reveled a significant day x group interaction (F1,6=7.02, Wilk's λ=0.631 , p=0.02, ω^2=0.369, 1-β=0.803). Independent post-hoc analysis revealed a significant improvement in the concussed subjects CES between days 1 and 10 (day 1 = 73.14 ± 5.73, day 10 = 78.71 ± 7.74 p=0.000). Repeated measures ANOVA revealed a significant day x group interaction for SOT somatosensory ratio ($F_{1,6}$=0.0431, Wilk's λ=0.651 , p=0.026, ω^2=0.349, 1-β=0.772). Pairwise post-hoc analysis revealed significant differences in the concussed group between days (day 1 = 1.09 ± 0.07, day 10 = 1.03 ± 0.04, p=0.044) and on day 1 of testing concussed subjects were significantly different than control subjects (concussed = 1.09 ± 0.07, control = 1.00 ± 0.00, p=0.009). There was a significant day x group interaction for the SOT VEST ratio ($F_{1,6}$=8.054, Wilk's λ=0.598 , p=0.015, ω^2=0.402, 1-β=0.848). Post-hoc analysis revealed a significant improvement between concussed subjects between day 1 and day 10 of testing (day 1 = 0.61 ± 0.09, day 10 = 0.80 ± 0.05, p=0.000), as well as a significant improvement between groups on day 1 (concussed = 0.61 ± 0.09, control = 0.71 ± 0.12, p=0.095). There were no other significant interactions for the CDP variables.

Discussion

This pilot study investigated visuo-motor processing and measures of CDP to analyze the relationship between the measures. We hypothesized that acutely concussed athletes, whom perform poorly on a SVMP task, would demonstrate a negative correlation with postural stability compared to healthy control subjects. The results indicate a trend towards a relationship between the SVMP overall RT and SOT CES on day 2 of testing in a concussed population. Figure 3 depicts a trend towards significance among the concussed group, as the scores on the SOT were impaired (lower score), the score on the SVMP was increased (higher score).
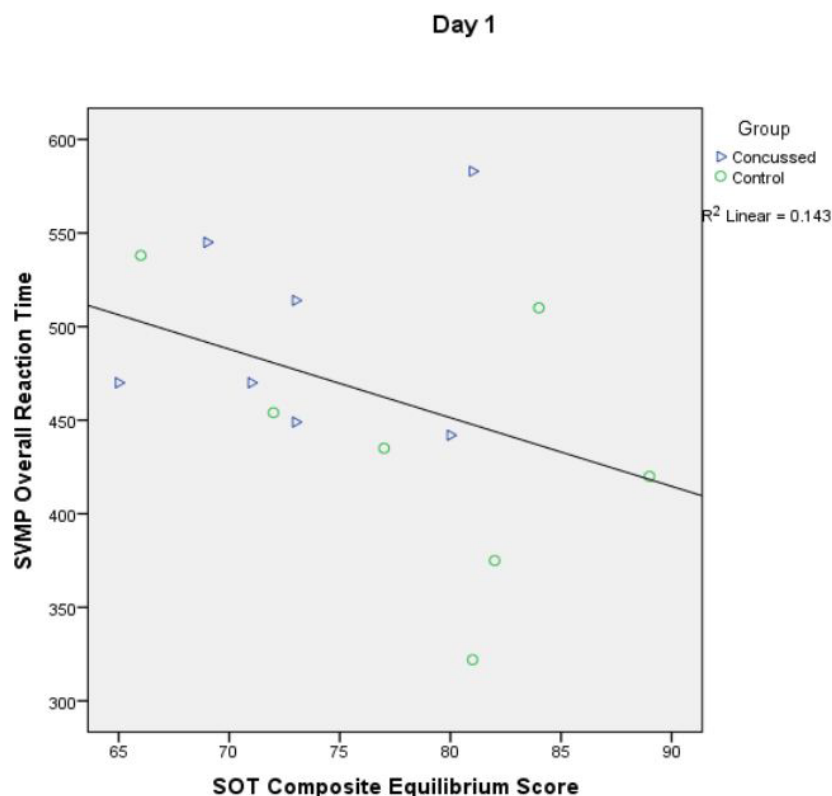

Figure 3: Correlation between SVMP RT and SOT CES Day 1

Following a concussion a battery of assessments has been recommended that should be administered to assist the health care provider with making a concussion diagnosis and monitoring the clinical course of recovery [12]. Included in the battery of assessment are athlete-reported post-concussion symptoms, cognitive performance, and balance [21]. Measures of balance reveal deficits immediately following the injury which may last anywhere from 3 to 10 days [11,12,25]. The deficits that occur in balance following a concussion are believed to occur as a result of impairments in the sensory systems to properly integrate information [26]. The objectives of using CDP measures are to identify which sensory system(s) are affected following a concussion and to track

the recovery of the balance impairments. However, the standard balance assessments using CDP do not address the underlying physiological changes which may be causing the balance impairments nor do they address impairments in the individual sensory systems separate from balance. Additionally, because the human visual system uses visual information from the surrounding environment, as well as cognitive information to interpret what is being seen and to navigate through the environment [27]. Problems arise for athletes when the ability to cognitively map their surroundings is impaired, resulting in delayed motor responses and impairments in fluid movements [28,29]. The ability of an individual to maintain upright balance and participate in normal gait is dependent on the individual's capacity to interpret their visual environment and objects in the environment. The visual system integrates that information into a sensory map which involves information from the visual system as well as information from the somatosensory and vestibular systems. The purpose of this study was to analyze the relationship between visual processing and upright postural stability in acutely concussed athletes through a simple visuo-motor processing task and computerized dynamic posturography. We hypothesized that acutely concussed athletes would demonstrate impairments in both visuo-motor processing and balance, while healthy control subjects would demonstrate no impairments in either visuo-motor processing or balance.

The balance assessments used in the current study (SOT) attempt to determine the integrity of integration of sensory information in an effort to identify impairments in the sensory systems following concussion. Results of SOT CES revealed significant improvement in the concussed group between day 1 and day 10 of testing (day 1= 73.14±5.73, day 10 = 83.57±2.15) which is similar to previous results of balance recovery between day 1-10 following concussion [4,25]. Similar results were also found on the SOM, VIS, and VEST ratio suggesting that immediately following a concussion physiological changes occurring in the brain are causing functional impairments but when the physiological changes begin to recover so do the functional changes. Contrary to what is published, no difference was found between groups on the SOT CES however as the CES is a weighted average of all trials, it is possible the CES is not sensitive to subtle changes in balance. Additionally, the variability between all subjects on day 1 of testing was higher than compared to day 10 confirming a learning effect on the test. Significant differences were noted on day 1 of testing between the concussed and control group on the SOT SOM and SOM VEST ratio. Concussed athletes scored higher on the SOM ratio compared to controls but scored lower on the VEST ratio. These impairments suggest that following concussion athletes may experience impairments in vestibular functioning and rely more heavily on input from the somatosensory system to maintain upright balance. While the SOT are successful in removing visual information, the result of the current study may have been influenced by involvement of the vestibular and somatosensory systems which cannot be truly isolated during the testing session future research should consider including methodology which attempts to provide altered vestibular inputs, e.g. using the Head Shake Sensory Organization Test (HS-SOT) to delineate vestibular dysfunction, to determine if there is a stronger relationship between concussion and vestibular function.

Acutely concussed athletes demonstrate functional differences between days while completing a SVMP task. The results of this study support the theory of delayed visual information processing immediately following a concussion [17]. Concussed athletes had significantly delayed reaction time on day 1 of testing compared to day 10 (day 1 = 496.18 ± 52.85, day 10 = 439.01±20.62). Furthermore, following a concussion concussed athletes demonstrated significant impairments on day 1 of testing in reaction time on left (day 1 = 484.97 ± 64.60, day 10= 429.35± 34.19), right (day1=474.88 ± 44.44, day 10= 413.76 ± 28.79), and ambiguous trials (day 1 =530.62.74 ± 62.74, day1= 472.30 ± 26.98). Improvements in balance following a concussion, were noted in the study as measured by the SOT CES (day 1 = 73.14 ± 5.73, day 10 = 78.71 ± 7.74) which is consistent with the previously reported recovery pattern of 3 to10days; however, the deficits in visuo-motor processing is a novel approach that has not been previously used for assessing acutely concussed athletes. SVMP task outcome measures including overall reaction time, reaction time left, reaction time right, and reaction time ambiguous all noted a significant improvement in the concussed group between day 1 and day 10. Improvement in reaction time may suggest that recovery of the neurometabolic cascade of concussion may be recovered by day 10

following the injury. Additionally, as the greatest impairments were noted on day 1 following the injury, it would suggest that the physiological changes are worst during that time. Additional significant findings were observed between groups on reaction time trials 81-100 (concussed = 531.31 ± 107.37, control = 422.35 ± 80.04), reaction time trials 101-120 (500.12 ± 54.17), and reaction time ambiguous stimuli (concussed = 530.22 ± 62.74, control = 452.58 ± 81.13). Visual processing is an essential attribute that athletes require to be successful in their sport. Any delay in visual information processing may lead to other functional impairments because areas of the brain which are responsible for visual processing are also partially responsible for coordinated movements, visually guided actions, and balance coordination [30,31]. These visual processing functions are extremely important in sports performance and participation. Additionally, visual processing is responsible for making a cognitive map of the surrounding environment. Therefore, an athlete suffering from a concussion may experience slowed visual processing caused by deficits in effective cognitive mapping, leading to difficulties navigating through space [32].

We hypothesized that concussed athletes who exhibited impairments in visuo-motor processing would also demonstrate deficits in balance deficits, but the correlation analysis did not demonstrate a statistically significant relationship on day 1 of testing; however, the results of the correlation analysis trended towards a significant relationship between SVMP and SOT measures on day 1 (Figure 3). Scores on the SOT CES in the concussed group on day 10 of testing were negatively correlated (r= -0.741, p= 0.057) with SVMP overall reaction time suggesting that as balance improves, reaction time improves as well (Figure 4). Additionally, SOT CES was negatively correlated with SVMP RT on trials 101-120 (r= -0.830, p= 0.021) suggesting that as scores on balance decrease, reaction time increases. However, the lack of a significant relationship between SVMP overall reaction time and SOT CES or mCTSIB mean COG sway velocity on day 1 of testing suggests that the SVMP measures a different underlying construct than CDP. The CDP measures were attempting to investigate the interactions among the sensory systems to identify if one or more of the systems were affected, the SVMP task determines if delayed information processing occurred and is therefore indirectly measuring physiological changes following a concussion. Assessment of balance is an integral component of assessment following a concussion [21], and we recommend that visuo-motor processing testing should also be evaluated to aid in decision making. A possibility exists that even if a concussed athlete demonstrates no impairments on balance; visuo-motor processing may be affected. Two subjects included in the analysis demonstrated deficits in SVMP overall reaction time but did not demonstrate deficits in balance as measured on the SOT. Future research should establish if the SVMP task can be used to diagnose concussion and make return-to-play decisions.
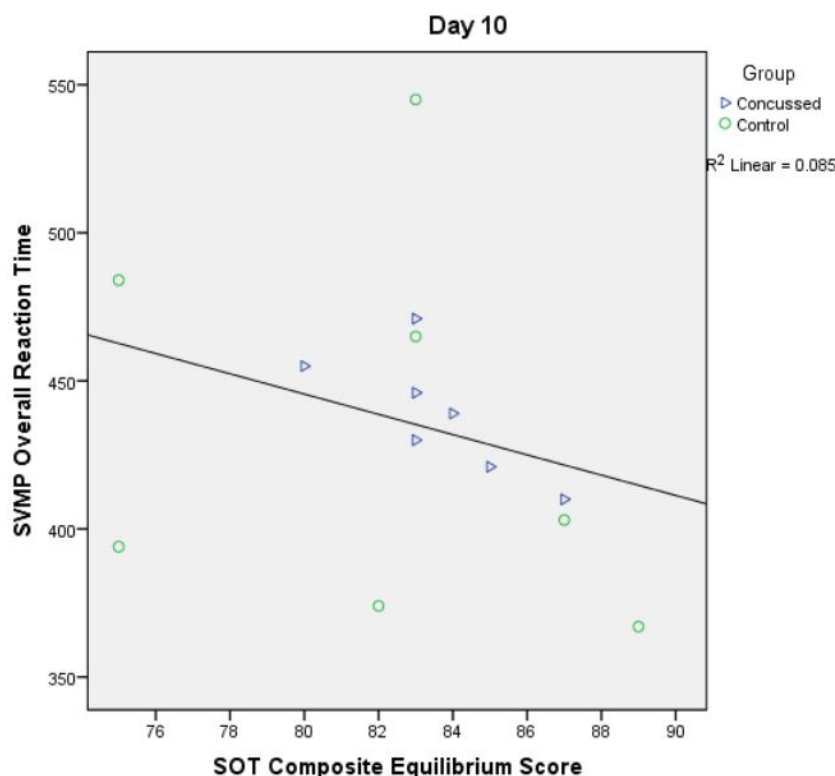

Figure 4: Correlation between SVMP RT and SOT CES Day 10

A limitation of this pilot study relates to the age of the subjects tested in the study, as the age of subjects (13 to 20 years) indicates that the results should only be generalized to that population. Future research should focus on identifying the relationship between SVMP and balance measures in different age population. Other factors which may have influenced the results of the study relate to the prior concussion history of the subjects and the type of visuo-motor stimuli used. Prior concussion history (>6months) was not determined among the control subjects and no attempts were made to match subjects (concussed to controls) based on

prior concussion history, as the cumulative effects of concussion have been previously reported [33], this may have influenced the results as athletes suffering from multiple previous concussions may exhibit additional impairments in balance and visuo-motor processing. The type of visual stimuli used in the current study during the SVMP task was based upon the work done by Pinkus and Patel (1997) [23]. To our knowledge, this test has not been previously investigated in acutely concussed subjects outside the investigator laboratory, however in unpublished work moderate reliability (ICC = 0.4-0.75) of the SVMP task was established. Balance assessment and SVMP task performance appear to be measuring two different underlying constructs which are independent from each other and both provide valuable information for identifying specific deficits following a concussion.

Conclusion

Acutely concussed athletes demonstrate impairments in visuo-motor processing and balance on day 1 of testing, as measured by the SVMP, and SOT tests respectively. The ability of an athlete to maintain upright balance and make a visual representation of the surrounding environment is essential for successful participation in athletics. The relationship between balance and SVMP task performance suggests that while the test may be evaluating different underlying independent constructs but both measures revealed specific deficits among concussed athletes compared to control athletes and trended towards a significant correlation. Balance is an important component of the post-concussion evaluation, and the addition of a simple visuo-motor processing task may provide further information about the nature and extent of deficits athletes experience in the initial 10 days following injury.

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