Visuo-Motor Processing Impairments Following Concussion in Athletes

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Abstract

Objective: Conduct a pilot study to determine if visuo-motor processing is altered in athletes following sports-related concussion.

Research design: A longitudinal matched cohort was used to assess 7 concussed and 7 matched control subjects.

Interventions: All subjects completed a simple visuo-motor processing task (SVMP). Each subject completed 120 randomized trials. Subjects were asked to identify which direction the motion occurred in (left/right). Repeated testing was conducted 10 days following initial testing.

Main outcome measures: Reaction time (overall, each grouping of 20 trials, ambiguous and unambiguous trials right/left), number of correct responses, and number of incorrect responses. A repeated measures ANOVA was conducted to determine differences between groups (concussed/control) and sessions (10 days apart).

Results: Concussed athletes have significantly delayed visuo-motor reaction time compared to control subjects and between days of testing.

Conclusions: Visuo-motor processing is impaired during the initial 10 days following a sports-related concussion. Concussed athletes demonstrate functional differences in SVMP task performance between testing days. An athlete may be placed at greater risk of injury if returned to sports participation with an impaired ability to quickly make decisions regarding direction of movement. Visuo-motor processing should be a routine component of concussion assessment and RTP decision making.

Keywords

Concussion; Vision; Traumatic brain injury; Sport

Introduction

Sport-related concussion rates in the United States have been reported as 300,000 concussions annually [1,2]. Approximately 50% of all concussions go unreported [3] by the athlete, so the true number of concussions may be much higher. Health care providers are faced with the intimidating task of diagnosing, managing, and making return to play decisions following sport-related concussions. The obstacle that health care professionals encounter in diagnosing concussion arises from the lack of biological markers or standardized assessment protocols, which accurately detect a concussion [3]. Concussion symptoms are highly variable among individual athletes and even among separate incidents in the same athletes, which poses a challenge for even the most experienced athletic trainer or sports medicine clinician to determine whether an athlete has sustained a concussion or not. Adding to the challenge is the lack of consensus of the definition of concussion. While most allied health providers believe that a concussion is synonymous with a mild traumatic brain injury, there are some professionals who believe concussion is a distinct injury and therefore requires its own definition [4]. The most widely accepted definition of concussion is defined by the Concussion in Sport Group (2009) as, “A complex pathophysiological process affecting the brain, induced by biomechanical forces. Common features of concussion include; may be caused by a direct blow to the head, face, neck, or elsewhere on the body with in ‘impulsive’ force transmitted to the head; typically results in rapid onset of short-lived impairments of neurological function that resolve spontaneously; may result in neuropathological changes but the acute clinical symptoms largely reflect a functional disturbance rather than structural injury; and result in a graded set of clinical symptoms that may or may not involve loss of consciousness, symptoms typically follow a sequential course” [4,5].

A concussion is a result of forces transmitted to the brain which cause both focal and widespread damage at the neuronal level [6]. The mechanism of injury that causes stretching and shearing of the axons results in diffuse axonal injury (DAI) [7] and triggers the onset of a neurometabolic cascade of concussion (NCC) [6]. Both DAI and NCC have been noted to cause impairments in axonal transmission speed [7]. Axons are responsible for transmitting information, including sensory information, throughout the brain and body. Any delay in the speed of transmission of neural signals may result in problems in sensory information integration, including information to and from the visual system. DAI results in disruption and depolarization of the cellular membrane and widespread damage to the axons in the brainstem, parasagittal white matter of the cerebral cortex, and corpus callosum [6] which result in functional impairments at the systems level. Cognitive deficits (e.g., disorders in memory), possible changes in vision [8], visuo-motor processing [9] and delays in information processing [10] may arise as a result of the changes at the physiological level.

The visual system relies on the ability to perceive and process visual stimuli quickly, and to cognitively interpret the stimuli to usable information; any delay in this process would likely cause clinical functional impairments. The human visual system uses visual information from the surrounding environment as well as cognitive information to interpret visual stimuli and to navigate through the environment [11]. The ability of an individual to maintain upright balance and gait is dependent on their capacity to accurately interpret their visual environment and objects in the environment. The ability of the visual system to identify objects and integrate that information into a sensory map involves information from the visual system, as well as information from the somatosensory and vestibular systems. Information from the vestibular system provides information about the position of the head and neck in space [12] while the somatosensory system provides information about the

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Subjects

Seven acutely concussed subjects [age (17.1 ± 3.0 years), height (174.0 ± 74.2 cm), weight (73.3 ± 23.8 kg)] participated in the pilot study. Subjects were included in the concussed group if they participated in an intercollegiate, interscholastic, or club sport and had been diagnosed with a concussion by a certified athletic trainer or physician sustained within the previous 48 hours. Subjects represented athletes from Women’s Basketball, men & women’s soccer, men’s hockey, and football. Concussed subjects reported 1 ± 0.2 previous concussions diagnosed in the past (but not within the previous year). Seven control subjects [age (17.3 ± 3.1 years), height (178.8 ± 11.6 cm), weight (77.9 ± 23.4 kg)] with similar age, sport, and gender participated. All subjects were volunteers whom signed a written informed consent or assent form. Human subject’s approval was obtained from the Office of Research Integrity at the University of Kentucky (IRB#12-0509) prior to beginning the study.

Control subjects had no self-reported history of a concussion within the previous year (previous concussion history >1year=0.8 ± 0.2 concussions), were not taking any medications that may affect balance (e.g., NSAIDS, antidepressants, anticonvulsants, vestibular suppressants, neurostimulants, antinetics) [22] taken within 2 hours of the scheduled testing, 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). All subjects reported no learning disabilities, ADHD, or brain surgery.

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 test. 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’, ‘t’, and ‘spacebar’) were removed. Visual acuity testing was conducted with the NeuroCom® InVision software, a component of the NeuroCom Smart Balance System (NeuroCom® International, Inc; Clackamas, OR). The hardware for the visual acuity testing included a head-mounted tracking device that determines the angle, distance, and velocity of head motion during the testing procedures.

Procedures

Subjects reported to the research laboratory on two separate occasions: 24 to 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 of postural stability comparable to control subjects within 24 hours to 10 days following a concussion [23-26]. 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 form containing questions about their health and medical history. Demographic information (e.g., height, weight, age, handedness, gender, and sport) was collected using standard techniques and entered into the E-prime software data files. Additionally, all subjects completed standardized visual acuity testing using the NeuroCom InVision system to determine adequate static and dynamic visual acuity. All subjects underwent additional testing which included self-reported symptom inventory (Head Injury Scale) and a balance assessment assessment (Sensory Organization Test (SOT) in order to facilitate recovery tracking.

Methods

Design

A longitudinal cohort pilot study design was used. The independent variables included time (with 2 levels: days 1 and day 10 following injury) and group (with 2 levels: concussed and control subjects). The dependent variables were derived from a simple visuo-motor processing task which included: reaction time, number of errors, number of responses right/left, and number of ambiguous responses (left and right directions).
To determine if visuo-motor processing was affected by the concussion, subjects complete a visual processing task, as developed by Pinkus et al. [27] in which they were seated at a distance of 24 inches from the computer screen with a modified keyboard positioned on a desk directly in front of the subject. The validity and reliability of the SVMP task had not been established prior to the initiation of this pilot study, the study was based upon previously published work of Pinkus et al. [27] which showed good face validity. 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 × 768 pixels. Mean luminance for the stimuli was 14 cd/m². Figure 1 represents ‘motion jumps’ that subject were asked to identify during the visuo-motor testing sequence.

Each trial 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 et al. [27]. 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) [28] occurring between each trial.

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 were instructed to press both the ‘l’ and ‘a’ buttons together. Testing lasted approximately 5 minutes and ended automatically after the completion of all 120 trials (40 per direction, ambiguous, unambiguous right, unambiguous left). Data derived from this test included: reaction time (m.sec), number of errors, number of overall responses (left and right directions), and number of ambiguous responses (left and right directions). All data were automatically extracted for analysis into an Excel spreadsheet by the Eprime software at the conclusion of the session. The order of the testing was counterbalanced between days and testing sequence to limit the potential influence of fatigue on the subject.

Data reduction

All data derived from the visuo-motor task were summarized by E-prime software and automatically exported into an Excel datasheet for data processing.

Statistical analysis

Descriptive statistics, measures of central tendency and variability were calculated to summarize the demographic characteristics of the sample. A repeated measures ANOVA, using a Bonferroni correction to control for the familywise error rate, was used to assess for differences between groups (concussed and control), and testing sessions (day 1, and day 10) on subjects’ performance of the visuo-motor processing task.

All statistical analyses were performed with SPSS software (PASW Statistics version 18.0, SPSS Inc., Chicago, IL). An a priori alpha level of p<0.10 was applied to all data to determine significant differences. An alpha level of p<0.10 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 are presented in Table 1. Separate two-way ANOVAs with repeated measures on the factor ‘time’ revealed a significant day by group interaction for: overall reaction time (F1,6=3.780, Wilk’s λ=0.759, p=0.076, ω2=0.241, 1-β=0.577), and reaction time for trials 81-100 (F1,6=5.475, Wilk’s λ=0.687, p=0.037, ω2=0.313, 1-β=0.712). Independent pairwise post-hoc analysis for these interactions revealed significant differences in the concussed group between day 1 and day 10. Overall reaction time was significantly faster on day 10 in the concussed group (496.18 ± 52.85, 439.01 ± 20.62), p=0.013) and reaction time on trials 81-100 was significantly faster on day 10 (532.31 ± 107.37, 421.00 ± 25.92, p=0.017). Reaction time on trials 81-100 was also significantly different on day 1 of testing between the concussed and the control group (concussed=532.31 ± 107.37, control=422.35 ± 80.04, p=0.051). No other significant interactions were noted for the SVMP outcomes.

A significant main effect on the variable ‘day’ was detected in the concussed group’s performance on the SVMP task. Pairwise post-hoc analysis showed significant differences between day 1 and day 10 on: SVMP reaction time left (day 1=484.97 ± 64.60, day 10=429.35 ± 34.19, p=0.023), SVMP reaction time right (day 1=474.88 ± 44.44, day 10=413.76 ± 28.79, p=0.014), SVMP reaction time ambiguous (day 1=530.22 ± 62.74, day 10=472.30 ± 226.98, p=0.034).

Significant main effects on the variable ‘group’ were noted for several SVMP test variables on days 1 and 10 of testing; concussed athletes were significantly different than control subjects on day 1 for SVMP reaction time for trials 101-120 (concussed=500.12 ± 54.17, control=439.81 ± 59.05, p=0.089), and SVMP reaction time ambiguous trials (concussed=530.22 ± 62.74, control=452.58 ± 81.13, p=0.069). On day 10 of testing, concussed subjects were significantly different from control subjects for SVMP reaction time trials 101-120 (concussed=484.77 ± 43.10, control=427.76 ± 68.77, p=0.089). No
Furthermore, concussed athletes demonstrated significantly slower reaction time on day 1 of testing compared to immediately following a concussion [9]. Concussed athletes had significantly delayed reaction time on day 1 compared to controls (day 1=496.18 ± 52.85, day 10=439.01 ± 20.62) (Figure 2). Furthermore, concussed athletes demonstrated significantly slower reaction time to the left (day 1=484.97 ± 64.60, day 10=439.01 ± 20.62) and to the right (day 1=474.88 ± 44.44, day 10=413.76 ± 28.79). Reaction time to ambiguous stimuli (day 1=530.62 ± 62.74, day 10=472.30 ± 26.97) and reaction time to the left and right when comparing acutely concussed athletes to healthy matched controls.

### Table 1: Descriptive Statistics for SVMP variables by Day and Group (mean ± SD).

<table>
<thead>
<tr>
<th>SVMP Variable</th>
<th>Concussed (n=7)</th>
<th>Control (n=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Reaction Time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Day 1</td>
<td>496.18 ± 52.85*</td>
<td>439.01 ± 20.62*</td>
</tr>
<tr>
<td>Day 10</td>
<td>439.01 ± 20.62*</td>
<td>433.14 ± 66.60</td>
</tr>
<tr>
<td>Reaction Time Trials 1-20</td>
<td>500.13 ± 74.85</td>
<td>431.67 ± 62.80</td>
</tr>
<tr>
<td>Reaction Time Trials 21-40</td>
<td>451.05 ± 73.82</td>
<td>437.63 ± 34.82</td>
</tr>
<tr>
<td>Reaction Time Trials 41-60</td>
<td>486.92 ± 58.61</td>
<td>427.02 ± 36.87</td>
</tr>
<tr>
<td>Reaction Time Trials 61-80</td>
<td>530.24 ± 147.81</td>
<td>431.30 ± 17.82</td>
</tr>
<tr>
<td>Reaction Time Trials 81-100</td>
<td>532.31 ± 107.37*</td>
<td>421.00 ± 25.82*</td>
</tr>
<tr>
<td>Reaction Time Trials 101-120</td>
<td>500.12 ± 54.17†</td>
<td>484.77 ± 43.10†</td>
</tr>
<tr>
<td>Reaction Time Right</td>
<td>484.97 ± 64.60†</td>
<td>429.35 ± 34.19†</td>
</tr>
<tr>
<td>Reaction Time Right</td>
<td>474.88 ± 44.44*</td>
<td>413.76 ± 26.79*</td>
</tr>
<tr>
<td>Reaction Time Ambiguous</td>
<td>530.22 ± 62.74*†</td>
<td>472.30 ± 26.96*†</td>
</tr>
<tr>
<td>Number Responses Left</td>
<td>59.00 ± 8.52</td>
<td>58.86 ± 11.36</td>
</tr>
<tr>
<td>Number Responses Right</td>
<td>59.71 ± 11.22</td>
<td>59.29 ± 7.30</td>
</tr>
<tr>
<td>Number Unanswered</td>
<td>60.14 ± 8.28</td>
<td>60.43 ± 5.83</td>
</tr>
<tr>
<td>Number of Incorrect Responses Left</td>
<td>0.86 ± 0.90</td>
<td>0.86 ± 0.90</td>
</tr>
<tr>
<td>Number of Incorrect Responses Right</td>
<td>1.14 ± 1.77</td>
<td>1.14 ± 1.22</td>
</tr>
<tr>
<td>Number of Amb Responses Left</td>
<td>19.71 ± 8.18</td>
<td>17.57 ± 6.27</td>
</tr>
<tr>
<td>Number of Amb Responses Right</td>
<td>19.86 ± 8.13</td>
<td>20.86 ± 10.24</td>
</tr>
<tr>
<td>Overall Reaction Time</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: aReaction Time measures in ms

**p<0.10; significant interaction group*day**

**p<0.10; significant difference between days of testing**

**†p<0.10; significant differences between groups (concussed and control)**

Other significant differences were noted between day or group (Table 1). Concussed athletes significantly improved on the SOT’s composite equilibrium score between days (day 1=73.14 ± 5.73, day 10=83.57 ± 4.8), and the overall total of symptoms reported (day 1=12.5 ± 5.7, day 10=1.8 ± 4.8) and had all returned to sports participation within the 10 days of testing.

The results of the additional testing reveal concussed athletes significantly improved on the SOT’s composite equilibrium score between days (day 1=73.14 ± 5.73, day 10=83.57 ± 4.8), and the overall total of symptoms reported (day 1=12.5 ± 5.7, day 10=1.8 ± 4.8) and had all returned to sports participation within the 10 days of testing.

**Discussion**

In this pilot study we investigated the effects of a single episode of sports-related concussion on visuo-motor processing. We hypothesized that there would be significant differences in SVMP task reaction time, total number of responses to the right and left, and number of ambiguous stimuli responses to the right and left when comparing acutely concussed athletes to healthy matched controls. Additionally, we hypothesized that concussed subjects would demonstrate slower reaction time and fewer errors (i.e., faster reaction time and fewer errors) on day 10.

Acutely concussed athletes demonstrate functional differences in SVMP task performance between days. The results of this pilot study support the theory of delayed visual information processing immediately following a concussion [9]. 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) (Figure 2). Furthermore, concussed athletes demonstrated significantly slower reaction time to the left (day 1=484.97 ± 64.60, day 10=429.35 ± 34.19) and right (day 1=474.88 ± 44.44, day 10=413.76 ± 28.79), and ambiguous trials (day 1=530.62 ± 62.74, day 10=472.30 ± 26.98). Figure 3 depicts the differences in reaction time for each stimuli type. 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 [29,30]. 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 [31].

The significant differences in overall reaction time on the SVMP task suggests that visual processing is initially impaired following a concussion (i.e., day 1 post-injury μ=496.18 ± 52.85 ms), but this impairment is short-lived (i.e., reaction time day 10 μ=439.01 ± 20.62 ms) and should recover to values comparable to control subjects (μ=433.14 ± 66.60 ms) within ten days following the injury. Concussed subjects were not statistically different than control subjects on day one for SVMP reaction time (concussed=496.18 ± 52.85, and control=436.32 ± 74.37 ms). Although not statistically significant, these results are clinically meaningful because symptoms of altered visuo-motor processing would likely become noticeable in a clinical setting and should be evaluated in future research. Figure 3 depicts the average reaction time on the SVMP task in 20-trial increments. The graph demonstrates that concussed athletes are not different in comparison to the control group on day 1 for overall SVMP task reaction time and continue to show no difference until 80 trials have been completed. During trials 81-100, concussed subjects were significantly different from control subjects (concussed=531.31 ± 107.37, control=422.35 ± 80.04 ms) on day 1 of testing suggesting that fatigue may be a factor following a concussion. Furthermore, reaction time on trials 101-120 was significantly different between concussed and control subjects on day 1 and day 10 (concussed, day=500.12 ± 62.74, day 10=439.81 ± 59.05 ms and control day 1=484.77 ± 43.10, day 10=427.76 ± 68.77 ms) suggesting that following a concussion the physiological changes occurring in the brain cause functional deficits which present during prolonged activity. Concussed subjects demonstrated faster reaction times on day 10 of testing, although they remained significantly slower than control subjects on trials 101-120, which may suggest that full recovery in subject’s reaction time had not occurred. Finally, the reaction time for ambiguous trails was significantly slower on day 1 of testing than the control group (concussed=530.22 ± 62.74 ms, control=452.55 ± 81.13 ms) and compared to day 10 (day 1=530.22 ± 62.74 ms, day 10=448.89 ± 77.21 ms) as depicted in Figure 4. Ambiguous trials require the subject to make a decision about the direction of the motion, having a delayed reaction time following a concussion provides support for delayed processing immediately following a concussion.

This pilot study was the first to examine visuo-motor processing changes in acutely concussed athletes in an attempt to better understand the physiological changes occurring in the brain following injury and the impact that these impairments have on a SVMP task. Visuo-motor processing includes components of working visual memory, visual attention, visual discrimination, and selective attention [31]. These components work collaboratively to help an individual form a visual representation of their surroundings, which in turn helps them navigate through space. Athletes are continually receiving visual information regarding other players, the location of the ball, and the fans or surrounding environment during athletic practice or competition, so it is imperative they be able to make the visual representation immediately to avoid possible collisions and intercept the ball or other players. Additionally, previous research [32] conducted on the ventral and dorsal pathways of the brain have linked visual perception and action to visual processing. This connection ultimately impacts how an individual responds to external visual perturbations for making a correct visual representation and how this ultimately influences functional movements. By identifying how these visual processing interactions are possibly affected following a concussion, our understanding of the functional deficits resulting from sport-related concussions will be greatly enhanced.

The SVMP task conducted in the current pilot study was based on the visual stimulus research done by Pinkus et al. [27]. This type of visual stimuli has been investigated in healthy adult subjects but has not been studied among acutely concussed athletes. The results of the current study demonstrated moderate test-retest reliability of the SVMP task, but the generalizability of the pilot study is limited to acutely concussed athletes between the ages of 13 and 20. Following an acute concussion, athletic trainers and sports medicine clinicians should assess both static visual acuity and visual processing through a SVMP task. Assessing visual processing and visual acuity following a concussion will help to identify impairments in the visual system...
which may be the underlying cause of other functional impairments (e.g., balance deficits).

**Conclusion**

Acutely concussed athletes demonstrate impairments in reaction time during a simple visuo-motor processing task between 1 and 10 days following the injury. The results of this pilot study suggest that athletes have delayed visual information processing following a concussion, even though balance and symptoms inventory scores had returned to normal. An athlete’s ability to navigate through their environment is imperative for successful and safe participation in athletics as sports have a highly dynamic and constantly changing environment. The ability to change and adapt quickly to the environment is one of the most important skills an athlete must possess for successful participation in athletics. This ability arises partially from the visual system which takes information about the surrounding environment and transfers that information to workable, usable information regarding orientation, speed, motion, color and trajectory. Current concussion assessment protocols do not incorporate visual testing approaches, but including visual processing and visual acuity testing in the post-concussion assessment battery will help in identifying impairments in visual processing. Through the process of identifying these visual processing impairments, the underlying cause for functional balance impairments that are common following the injury may be revealed.

**Declaration of Interest**

The authors report no conflicts of interest.

**References**