Three-dimensional multiple object tracking in the pediatric population: the NeuroTracker and its promising role in the management of mild traumatic brain injury

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Introduction

Clinicians working with children and adolescents with mild traumatic brain injuries (mTBI) often face the challenge of determining when recovery is sufficient to clear them for safe return to activities (e.g., sport, school, leisure). The current literature on mTBI management prioritizes the assessment of self-reported postconcussive symptoms when clearing children and adolescents for return to their activities [1]; however, this method can be prone to under-reporting [2]. Moreover, recent studies have shown that although children are cleared for return to activities upon resolution of their postconcussive symptoms, cognitive and motor deficits, unidentifiable through routine concussion testing, can persist for weeks [3–5]. This places injured children and youth at risk for premature return to activities and risk of re-injury [5].

Current assessment measures have yielded inconsistent results when it comes to determining readiness to resume activities after mTBI. This lack of agreement thus encouraged researchers to look deeper into newly available measures such as, among others, fluid biomarkers [6,7] and vision-related assessment [8,9]. The latter (vision based) area of research seems promising as it focuses on more ecological and cost-efficient methods for concussion tracking and recovery, mainly looking at oculomotor function. As mTBI symptoms can be expressed through vision and neuro-ophthalmologic signs and symptoms, vision-related assessments are an intriguing potential assessment tool. At this time, vision-based concussion diagnosis and management tools still require further investigation [8]. Although findings from vision-based assessment can weigh in on the clinical management of pediatric mTBI, these assessments should not yet be relied upon solely when clearing children to return to activity [8,9]. Hence, there is a need for clinicians working with the pediatric mTBI population for a measure of recovery that involves ecological paradigms and that could weigh in more significantly in granting readiness to go back to activities.

Faubert and colleagues, through their innovative work with elite sports teams, military personnel, and aging adults, have developed a three-dimensional multiple object-tracking (3D-MOT) tool, the NeuroTracker, that shows promise for both mTBI assessment and treatment tool. To date, no research has looked at 3D-MOT in a pediatric mTBI population. Thus, the aim of this study was to examine 3D-MOT learning in children and youth with and without mTBI. Thirty-four participants (mean age = 14.69 ± 2.46 years), with and without mTBI, underwent six visits of 3D-MOT. A two-way repeated-measures analysis of variance (ANOVA) showed a significant time effect, a nonsignificant group effect, and a nonsignificant group-by-time interaction on absolute speed thresholds. In contrast, significant group and time effects and a significant group-by-time interaction on normalized speed thresholds were found. Individuals with mTBI showed smaller training gains at visit 2 than healthy controls, but the groups did not differ on the remaining visits. Although youth can significantly improve their 3D-MOT performance following mTBI, similar to noninjured individuals, they show slower speed of processing in the first few training sessions. This preliminary work suggests that using a 3D-MOT paradigm to train visual perception after mTBI may be beneficial for both stimulating recovery and informing return to activity decisions. NeuroReport 00:000–000 Copyright © 2018 Wolters Kluwer Health, Inc. All rights reserved.
treatment [10–12]. In 3D-MOT, individuals must allocate their attention among multiple moving targets among distractors moving across the visual field. This 3D-MOT task, involving speed of information processing, visual perception, and dynamic visual processing, has shown potential to promote brain plasticity, as well as cognitive function in adults [13], in addition to showing a very clear and reproducible 3D-MOT learning curve across diverse populations (young adults, elderly, athletes) [10–12,14]. In line with Faubert and Sidebottom’s [12] initial declaration, these studies have consistently shown that optimal training gains are reached within the first five training sessions on the NeuroTracker [11–15]. Moreover, this research has found that training gains stabilize over time and follow a predictable learning curve on the basis of age group [11] and physical activity level [10,12].

Faubert and Sidebottom hypothesized that 3D-MOT using the NeuroTracker could be a suitable candidate for management and return to play decisions because of its controlled and accurate retest ability, its precise and consistent perceptual-cognitive training conditions, and the presumption that this task provides mild cognitive stimulation, a concept that was previously suggested to improve recovery after mTBI [12]. Legault and Faubert [14] previously established that training gains on the NeuroTracker could transfer to improvements on biological motion perception through identification of dynamic visual cues in the elderly population. This becomes pertinent when drawing a parallel to the management of mTBI, where children who sustain this condition are at a higher risk of experiencing persisting cognitive and spatial navigation deficits [3–5]. However, to date, there are no scientific data to support the use of 3D-MOT for either mTBI assessment or treatment. Hence, the aim of this study was to compare 3D-MOT learning gains in the postacute phases of mTBI with those of healthy controls during NeuroTracker training.

Table 1 Overall and subgroup (controls vs. post-mTBI) participants’ characteristics

<table>
<thead>
<tr>
<th></th>
<th>Overall</th>
<th>Controls</th>
<th>Post-mTBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ± SD) (years)</td>
<td>14.69 ± 2.46</td>
<td>12.79 ± 2.19</td>
<td>16.01 ± 1.66</td>
</tr>
<tr>
<td>Sex [n (%)]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>26 (76)</td>
<td>13 (93)</td>
<td>13 (63)</td>
</tr>
<tr>
<td>Female</td>
<td>8 (24)</td>
<td>1 (7)</td>
<td>7 (37)</td>
</tr>
<tr>
<td>Time since injury (mean ± SD) (months)</td>
<td>–</td>
<td>–</td>
<td>2.21 ± 2.46</td>
</tr>
</tbody>
</table>

mTBI, mild traumatic brain injury.

Participants and methods

Participants

Thirty-four physically active English-speaking or French-speaking participants aged 9–18 years (76% males, mean age: 14.69 ± 2.46 years) were recruited for this study from the Greater Montreal and Greater Victoria regions. Twenty control participants (93% males, mean age: 12.79 ± 2.19 years) and 14 participants who had a recent history of mTBI and were symptom free (63% males, mean age: 16.01 ± 1.66 years) were included in this study (Table 1). Participants had normal or corrected to normal vision, with no history of learning disability, attention deficit disorder with or without hyperactivity, cognitive disabilities, and learning and/or behavioral problems. Control participants had no history of mTBI in the previous year. Participants were recruited through word of mouth and advertisements in local sports organizations. Ethical approval was obtained from both the Montreal Children’s Hospital and the Victoria University Human Research Ethics Board.

Study procedures

Eligible and consenting individuals underwent cognitive perceptual training using the CORE mode of the NeuroTracker system (CogniSens, Montreal, Canada). Participants wore active stereoscopic glasses and were seated in a dark room 160 cm away from a 60 inch TV screen with eyes positioned at the center of the screen.

Although optimal training gains are achieved within the first five training sessions in adult populations [9–14], limited information is available on training gains within the pediatric population. Upon visual inspection of learning curves from pilot unpublished work carried out on pediatric participants in our labs, we opted for six training visits. At each visit, participants completed three blocks of 20 trials of 3D-MOT that took ~8 min and followed identical procedures, with a rest period from 2 to 5 min in between each blocks. A mean speed threshold, on the basis of the average performance of the three blocks, was calculated at each visit. Each appointment took about 30 min, and occurred every 3–7 days. First, the participant was presented with eight identical yellow balls placed randomly on a television screen (presentation phase). Second, four of eight balls turned red and were highlighted with a white halo for 2 s to identify the targets to track (identification phase). Third, the four target balls returned to yellow and all eight balls moved and bounced around the screen for 8 s (removal phase). Fourth, the balls stopped moving and the participant was asked to name the target balls that were formerly identified (stoppage phase). Finally, the participant was provided feedback about the correct target balls for 3 s (Fig. 1). Speed thresholds, the outcome variable of interest, were calculated using a one-up one-down staircase procedure [16], such that after each correct response (i.e., four target balls identified accurately), the speed of the balls was increased by 0.05 log and after each incorrect response, the speed of the balls was decreased by 0.05 log. The process resulted in a threshold criterion of 50%. After 20 trials, the speed threshold was calculated as the mean speed threshold (m/s) from the last four inversions.
Speed thresholds training gains on the 3D-MOT task were analyzed using both absolute (unprocessed speed thresholds) and normalized values (processed speed thresholds). The latter value represents performance relative to the mean of visit 1 rather than the actual speed threshold calculated at each visit. Hence, with respect to normalized gains, visit 1 is the zero value and gains/losses at subsequent visits vary on the basis of the participants’ performance on the initial visit.

**Analysis**

Groups were significantly different with respect to age, with the post-mTBI group being slightly older than the control group. K. Kristina, C. Hilary, O. Kimberly, D. Laila, R. Allison, C. Tanya, F. Jocelyn, I. Gagnon, C. Brian (unpublished data) previously showed that the initial absolute speed thresholds tend to increase with age. As, although significant, the age differences between our two groups were fairly small, and the number of study participants was limited, we opted not to control for age. To establish whether training gains on the 3D-MOT task were different between the post-mTBI and the control groups, a repeated-measure ANOVA (time × control groups) was performed, with significance level set at \( p < 0.05 \), where all criteria for ANOVA were fulfilled. Post-hoc independent-sample \( t \)-tests were performed to look at the performance at each visit between the two study groups.

**Results**

A two-way repeated-measure ANOVA with significance level set at \( p < 0.05 \) did not indicate significant differences between the two groups on absolute speed thresholds \( [F(1,32) = 2.635, P = 0.114, \eta_p^2 = 0.046] \) nor a group-by-time interaction \( [F(1,32) = 0.044, P = 0.836, \eta_p^2 = 0.0155] \) (Fig. 1). However, a significant time effect was observed \( [F(1,32) = 40.231, P < 0.001, \eta_p^2 = 0.686] \), showing that both groups improved on the task over time. In contrast, when looking at normalized values of speed thresholds, a two-way repeated-measure ANOVA showed main effects of group \( [F(1,32) = 4.427, P = 0.043, \eta_p^2 = 0.841] \) and time \( [F(1,32) = 37.589, P < 0.001, \eta_p^2 = 0.855] \), and a significant group-by-time interaction \( [F(1,32) = 6.307, P = 0.017, \eta_p^2 = 0.343] \); the mTBI group showed lower normalized speed thresholds over the course of training. Ad-hoc independent \( t \)-tests showed a significant-group difference on absolute speed thresholds only at the second visit \( (t = 2.622, P < 0.05, d = 0.12) \) (Table 2), with nonsignificant differences between groups at subsequent visits, and similar training gains slopes (Fig. 2).

**Discussion**

Our results indicate that both healthy youth and youth with mTBI can benefit from 3D-MOT training, with significant time effects. Our findings also show that although youth can improve their 3D-MOT performance with repeated testing/training following mTBI, compared with noninjured youth, they show slower speed of processing in initial training sessions. Specifically, the control group showed a 79% increase in speed thresholds over the course of six training appointments, whereas the post-mTBI group improved by 66%. Within the first hour of training (two visits), a 33% increase in the speed threshold was observed in controls and 0.06% in participants who recently sustained an mTBI. In their 2011
study, Beauchamp and Faubert [17] indicated that elite adult athletes improved by 50% within their first hour of training. This difference could be explained by the age of our participants or differences in their participation in activities and sports requiring multiple object tracking.

Post-mTBI youth showed similar training gains at visits 3, 4, 5, and 6 as noninjured controls. The significant difference in the normalized speed threshold at the second visit was observed even though participants were in the postacute phases of mTBI, suggesting a maintenance of training effects before the third visit. Learning gains slopes were similar for both groups, indicating that over the course of six 3D-MOT training sessions, post-mTBI participants can show training patterns similar to healthy controls. However, as the post-mTBI group showed significantly lower speed thresholds at the second visit, we can conclude that their training gains pick up with repeated training and mimic those of noninjured individuals over time. This phenomenon could be because of natural recovery of mTBI or could possibly be an effect of repeated training on the NeuroTracker; further work is necessary to explore the latter hypothesis.

On average, participants in the mTBI group had sustained their injury 2.21±4.32 months before their participation. Knowing that the expected window of recovery after mTBI is about 10 days [1], we can assume that most participants in this group were back to activities (sport, school, etc.) upon participation in this study. These results provide further support that cognitive deficits in youth post-mTBI may persist, even upon return to activities, and help stress the importance of developing assessment tools to better assess clinical recovery in pediatric mTBI [3–5].

Study limitations included sample size, age differences between groups, and a variable time since injury in mTBI participants. Further research with a larger sample, earlier in the recovery process, and less variable time since injury could help reinforce the present findings. In addition, on the basis of previously discussed work by K. Kristina, C. Hilary, O. Kimberly, D. Laila, R. Allison, C. Tanya, F. Jocelyn, I. Gagnon, C. Brian (unpublished data), older teenagers show higher initial speed thresholds than younger teenagers. In our study, the post-mTBI group was significantly older than the control groups; however, the latter still showed higher training gains and speed thresholds in the initial visits. Hence, it is possible that the effect of age in this study may be masking an even greater effect of group on the 3D-MOT task. Despite these limitations, this preliminary work suggests that a brief 3D-MOT training paradigm may be beneficial for monitoring recovery following mTBI and warrants further investigation.

To our knowledge, this study is also the first to examine 3D-MOT through NeuroTracker in the pediatric population, showing that it is possible to improve speed thresholds in both the healthy and the postinjured brain. To establish 3D-MOT as a safe and effective treatment tool for pediatric mTBI, future work will need to examine the effect of 3D-MOT training on symptom recovery and other outcomes following mTBI, including days to return to play, cognitive function, and measures of brain plasticity. Work in healthy university students has shown that 3D-MOT improves attention, working memory, and visual processing speed, and produces changes in cerebral resting-state brain function [18]. In addition, as stated previously, a study with the aging brain showed that training gains through this paradigm can transfer to a cognition-related task, useful in daily activities of this population [14]. However, the effect of 3D-MOT on mTBI outcomes has not yet been explored. As is true of mTBI treatments in general [1,19], a well-designed randomized-controlled trial is necessary to establish 3D-MOT as a safe and effective treatment alternative to current best practice for pediatric mTBI (i.e. rest and watchful waiting).

Conclusion
This promising preliminary work suggests that (i) 3D-MOT could serve as an inexpensive and easily accessible tracker of recovery following pediatric mTBI and (ii) children may benefit from 3D-MOT training after mTBI. 3D-MOT warrants further exploration both as an assessment and as a treatment tool for pediatric mTBI.

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Conflicts of interest
J.F. is a Scientific Officer for CogniSens Inc., the producer of the commercial version of the 3D-MOT system.
used in this study. In this capacity, he holds shares in the company. For the remaining authors, there are no conflicts of interest.

References
11 Legault I, Allard R, Faubert J. Healthy older observers show equivalent perceptual-cognitive training benefits to young adults for multiple object tracking. Front Psychol 2013; 4:323.