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Concussion and Concurrent Cognitive and Sport-specific Task Performance in Youth Ice Hockey Players: A Single-case Pilot Study

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Abstract

Background: Concussion is common in the sport of ice hockey and can cause deficits in cognitive function. In most situations, ice hockey participation requires the performance of more than one skill at a time. It has been reported that following concussion in athletes, performance deficits arise when locomotor and cognitive tasks are performed concurrently that may have otherwise gone unnoticed if assessed in isolation of one another. The purpose of this pilot study was to explore the effect of concussion on cognition during concurrent ice hockey specific tasks in youth ice hockey players.

Methods: This single case pilot study compared the performance of 4 male youth ice hockey players who had experienced a concussion in the previous ice hockey season (mean age=11.7 ± 0.3 years; mean time since injury=92.5 ± 49.1 days) to a group of 10 non-injured controls (mean age=11.8 ± 0.8 years). Participants completed a randomized combination of three ice hockey specific tasks while concurrently completing a visual interference task (modified Stroop task).

Results: Participants who experienced a concussion within the previous ice hockey season and were ≤ 58 days post-injury demonstrated significantly poorer cognitive performance (increased cognitive dual task cost) across all conditions when completing the visual interference task concurrently with ice hockey specific skills ($p \leq 0.05$).

Conclusion: This study acts as an initial step towards the development of a sport-specific assessment of functional performance following concussion in youth ice hockey players to help inform safer return to play.

Keywords: Athletes; Youth; Concussion; Return to play; Ice hockey; Ecological validity

Introduction

According to most recent international consensus [1], concussion is defined as "a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces" (p. 250) and can result in short or long term symptoms (somatic, cognitive and/or emotional), behavioural changes and cognitive impairment. Functionally, these outcomes can make it difficult to participate in activities of meaning and importance. It has been estimated that in the United States alone, up to 3.5 million concussions occur each year as a result of recreation and sport participation [2]. Further, it has been suggested that the potential for concussion is greatest in athletic environments where collisions are common [3]. Specific to the sport of ice hockey, concussion has been reported as the most common specific injury amongst youth [4], where high speed play, environmental hazards (e.g., ice, boards etc.) and frequent body contact have been suggested as contributing factors [5].

Returning to play following a concussion is a priority to many athletes young and old, however caution when reintegrating into full sport participation must be taken. Returning to sport too soon (e.g., prior to recovering from a concussion) can contribute to exacerbated symptoms and delayed recovery from the current injury [6], and more seriously, may contribute to a secondary concussive event. Second-impact Syndrome can occur when an athlete sustains a second concussion prior to the resolution of symptoms as a result of an initial concussion [7], and can lead to catastrophic outcomes [8]. Further, from a functional perspective, as cognitive deficits, such as slowed reaction time [9], can be present following concussion, returning to play prior to the resolution of these deficits may limit one's ability to process and respond appropriately to potentially injurious situations (e.g., contact from an opponent during hockey competition), where a secondary concussive event may result. To avoid potential negative outcomes associated with returning to play too soon, appropriate concussion management is recommended [1,7].

A concern with the traditionally recommended approach to returning to play after a concussion (Table 1) is its inherent reliance on self-reported post-concussion symptom ratings. Further, specific

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Rehabilitation Stage	Activity/Exercise
(1) No activity	Complete rest (cognitive and physical)
(2) Light aerobic exercise	Walking, cycling (stationary) or swimming at <70% maximum predicted heart rate
(3) Sport-specific exercise	Skating drills in hockey, running drills in lacrosse or soccer (no head impact activities)
(4) Non-contact training/practice	More complex training drills (passing drills etc.) Light resistance training
(5) Full contact training/practice	Following medical clearance, participate in full training/practice activities
(6) Return to play	Game play

*Modified version of the recommendations presented at the Fourth International Conference on Concussion in Sport [1]

Table 1: Gradual return to play protocol.

to youth ice hockey, concern for players not reporting incidents indicative of concussion and related symptoms has been suggested as a contributor to considerable underreporting of concussions within this population [5]. An additional concern with this approach to returning to play following a concussion and its reliance on post-concussion symptom resolution is that all impairments associated with concussion may not resolve in concert with symptoms. When examining cognitive performance amongst 61 concussed athletes, Collie et al. [10] reported that participants demonstrated deficits in the cognitive domain of divided attention (attending to two tasks at one time) despite no longer reporting post-concussion symptoms, indicating that the recovery of cognitive function can lag behind the resolution of post-concussion symptoms. In sport, the ability to divide attention between several concurrent tasks is often essential, where a decline in one's ability to do so may put an athlete at risk for a secondary concussive event.

The need for further objective information specific to post-concussion recovery has led to recommendations for the use of neuropsychological assessment in order to determine cognitive recovery (in addition to symptom resolution) and to contribute further to return to play decision making [1,11-13]. However, the isolated and clinical nature of neuropsychological assessments (e.g., assessing a single domain of cognitive performance in the absence of concurrent cognitive and motor demands) may provide only a limited view of whether an athlete is truly ready to return to sport competition. According to Haggard et al. [13], "most daily living tasks involve concurrent movement and cognition, yet quantitative assessment after brain injury typically treats these functions separately" (p.485). Performance in clinical settings does not necessarily transfer to performance during daily activities in other settings, where differences exist in the demands inherent to a given environment (e.g. obstacles, visual/auditory distractions etc.) [14]. With isolated clinical evaluation of cognitive performance comes the potential for masking performance deficits that may occur with the multiple demands of dynamic real-world environments.

Recent studies have shown that when the performance of concussed athletes is assessed using concurrent real-world cognitive and motor tasks, deficits arise that may have otherwise gone unnoticed [15-17] using traditional isolated tests of cognition, and these deficits remain even once post-concussion symptoms and impaired isolated cognitive performance resolve [16,17]. These findings suggest that in order to generate an accurate index of readiness to return to play following concussion, athletes must be assessed in a manner that is ecologically valid and that provides cognitive and motor challenges similar to those found in sport participation. One approach towards improved ecological validity and the more accurate assessment of functional ability following concussion is the use of dual-task methodology [18] and the use of sport-specific skills.

Due to the visible and concrete physical demands of sport performance, the contribution of cognitive processes can often be overlooked. Sport performance, including playing ice hockey, can be considered highly cerebral, where cognitive abilities such as attention allocation, planning, reaction time and reaction accuracy can contribute to the differentiation between elite and novice athletes [19]. Specific to sport-related concussion in youth ice hockey players, it is possible that impaired cognitive abilities, such as a declined ability to respond quickly and appropriately to opponents and navigate away from injurious situations, could put one at risk for injury during ice hockey competition. Further, it has been reported that functional performance deficits remain in athletes when performing cognitive and motor skills concurrently despite resolution of post-concussion symptoms and deficits on isolated neuropsychological assessment [17]. As a result of the importance of cognitive function in sport and the implications of concussion on ice hockey performance and injury risk, the direct exploration of the influence of concussion on cognitive function during concurrent ice hockey task performance is warranted.

The purpose of this single case pilot study was to explore the effect of experiencing a concussion within the previous ice hockey season on the cognitive performance of youth ice hockey players while completing concurrent ice hockey specific tasks. It is anticipated that the findings of this study may be viewed as an initial step towards a greater understanding of the influence of concussion on cognitive performance within a real-world context and inform both further study and the development of sport-specific measures of readiness to return to play for youth ice hockey players.

Methods

Participants

A convenience sample of 14 competitive youth male ice hockey players from the Greater Toronto Hockey League and the Mississauga Hockey League participated in the study. Participants were divided into two groups: Those who experienced a concussion during the previous ice hockey season (4 concussed participants; mean age=11.7 ± 0.3 years; mean time since injury=92.5 ± 49.1 days) and non-injured controls with no reported history of concussion (10 non-injured control participants; mean age=11.8 ± 0.8 years). Data for 7 of the 10 control participants was collected at an earlier date and has been reported previously [20]. Within the ice hockey leagues from which the participants were recruited, competitive youth ice hockey teams participate in three divisions based on skill level. These divisions are A, AA and AAA, where A represents the lowest skill level and AAA represents the highest skill level. Only male youth ice hockey players who participated on A and AA hockey teams were enrolled in this study to provide a more accurate representation of the typical male youth representative level ice hockey player. Participants were included within the concussed group if they had experienced a concussion during the previous ice hockey season (diagnosed by a medical practitioner), while participants were included within the non-injured control group if they reported no history of concussion. Further, all participants in the concussion group were no longer reporting post-concussion symptoms and had returned to full daily activities including ice hockey participation. Exclusion criteria included any self-reported neurological or musculoskeletal problems or taking medication affecting alertness, cognitive or motor abilities. Participant characteristics are presented in Table 2. Ethics approval was obtained from the University of Toronto Health Sciences Research Ethics Board and all participants' legal guardians signed informed consent prior to data collection. In addition, the study was explained to

Participant	Days post-concussion	Age (years)	Height (m)	Weight (kg)	Stickhandling side preference
Concussion group (n=4)					
1	44	12.0	1.38	30.4	Right
2	58	11.5	1.51	44.2	Left
3	123	11.9	1.46	41.5	Right
4	145	11.5	1.53	32.4	Left
Mean	**92.5**	**11.7**	**1.47**	**37.1**	**-**
SD	**49.1**	**0.3**	**0.07**	**6.8**	**-**
Non-injured control group (n=10)					
5	-	12.2	1.54	45.7	Left
6	-	11.7	1.44	34.8	Left
7	-	13.2	1.57	47.0	Left
8	-	11.2	1.50	31.8	Left
9	-	12.3	1.62	62.9	Left
10	-	10.7	1.35	32.7	Left
11	-	12.1	1.50	38.5	Left
12	-	12.2	1.75	72.3	Right
13	-	11.9	1.64	50.5	Left
14	-	10.9	1.42	40.9	Left
Mean	**-**	**11.8**	**1.53**	**45.7**	**-**
SD	**-**	**0.8**	**0.12**	**13.3**	**-**

Table 2: Participant characteristics (n=14 males).

the youth participants and their assent was obtained in order to proceed with the study protocol.

Procedure

The protocol used was designed as a replication of a previous study specific to concurrent cognitive and motor performance during hockey skill performance in healthy youth ice hockey players [20]. Participants were asked to complete a series of combined ice hockey related tasks of various complexities along with a visual interference task in order to emulate the real-world and cognitive demands required during ice hockey participation. Three tasks: (1) skating; (2) avoiding a fixed obstacle in skating path (right and left); and, (3) stickhandling an ice hockey puck were completed in combination with each other while concurrently completing a visual interference task (modified Stroop task; [21], creating a total of six conditions. All possible task conditions, along with the number of concurrent tasks completed, are presented in Table 3.

Participants completed three trials of each possible condition for a total of 18 trials (6 conditions × 3 trials per condition=18 total trials). Trials were completed in random order with the participant informed by the researchers of which concurrent tasks were to be completed prior to completing each trial. Prior to the completion of the study protocol, all participants completed a warm-up consisting of light skating and stretching, a practice trial of the visual interference task while standing still and three task protocol practice trials: (1) unobstructed skating; (2) skating while stickhandling and avoiding the obstacle to the left; and, (3) skating, while avoiding the obstacle to the right and completing the visual interference task.

Description of tasks

Skating: During all trials, participants were asked to skate forward at full speed along a 16.50 meter skating path mapped onto a standard ice hockey rink. From a stationary start position, participants were asked to skate at full speed from start to finish of the skating path without stopping. The start position of the skating path was marked clearly on the ice using heavy permanent marker and the end position was the front of an ice hockey net. As described in the previous study [20], full speed skating was used to reduce variability in selected skating speeds across task protocol conditions. Further, two cones approximately 1.50 meters apart were placed at 4.20 meters into the skating path from the start position. From the start position, participants were instructed to skate forward through these cones towards the end position (ice hockey net) in order to decrease variability in the trajectory of the skating path and to help promote forward skating.

Obstacle avoidance: During trials that included avoiding an obstacle, participants circumvented a fixed cylindrical obstacle placed within the skating path at 8.40 m from the start position. The custom built obstacle (height: 1.45 m, diameter: 0.30 m) was made of a thick cylindrical fabric shell filled with a stack of five inflated beach balls. Sandbags were placed at the bottom of the obstacle to stand them upright. The same obstacle was used previously with healthy youth ice hockey players [20] and a similar obstacle has been used previously with adult athletes [22]. Prior to each trial that included obstacle avoidance, the participants were provided instruction specific to which direction they were to circumvent the obstacle (left or right). Participants were asked to skate at full speed and to pass through the two cones (placed at the 4.20 metres into the skating path) prior to circumventing the obstacle and arriving at the skating path end position. Again, the cones were used in order to limit the variability in skating path trajectory during the task and to promote both forward skating and explicit obstacle circumvention.

Stickhandling ice hockey puck: During trials that included stickhandling an ice hockey puck, participants were asked to use their own ice hockey stick to carry a standard ice hockey puck from the start position to the end position of the skating path. Further, once arriving at the end position of the skating path, participants were asked to place the ice hockey puck on a clearly marked 'X' centered at the front of the ice hockey net. This ice hockey puck placement was used during stickhandling trials to keep participants from shooting the puck at the ice hockey net prior to or upon reaching the end position of the skating path in order to both promote consistency when arriving at the skating path end position and to avoid errant ice hockey pucks striking experimental equipment or members of the research team.

Visual interference: The visual interference task consisted of a modified Stroop Color Word Test, Interference Condition [21] projected on a large screen directly in front of the participants at the end of the skating path. A data projector (Epson Powerlite 77c) was placed on a table directly behind the ice hockey net at the end position of the skating path. The large presentation screen (1.52 m × 1.35 m) was placed at 2.83 meters away from the data projector. The task consisted of the words "red", "green" and "blue" being projected onto the screen in colors either congruent (e.g., word "red" written in red) or incongruent (e.g., word "red" written in blue) with the words lexical meaning. Participants were asked to verbally identify the color that the word was written in as quickly as possible. Trials were accompanied by a visual and auditory

Number of concurrent tasks	Tasks completed				
	Visual interference (Stroop)	Skating	Stickhandling Ice Hockey Puck	Obstacle avoidance right	Obstacle avoidance left
2	x	x			
3	x	x	x		
	x	x		x	
	x	x			x
4	x	x	x	x	
	x	x	x		x

Table 3: Task protocol conditions.

countdown to identify the start of the trial (e.g., when to begin skating towards the end position and when to begin verbally responding to visual stimuli). Visually, this countdown presented the numbers 3, 2, then 1 on individual slides, followed by a separate slide presenting the word «GO». Each slide within the countdown was presented 1 second apart from each other and was paired with an auditory beep. Upon the completion of the countdown, the color words were projected onto the screen and a separate slide for each word was presented at a rate of one word every second. Prior to completing the visual interference task concurrently with the other experimental tasks (e.g., while skating etc.), all participants completed the visual interference task during a static trial (while standing) in order to determine baseline performance. During the static trial, the presentation of word stimuli slides was stopped after five words, while during skating trials the presentation of the word stimuli slides was stopped when the participant reached the end position of the skating path. All visual and auditory stimuli slides were created using PowerPoint 2007 (Microsoft Corporation, Redmond, WA). Verbal responses to the visual stimuli were recorded using a portable voice recorder (Panasonic RR-U360) worn by the participants during all trials and all trials were video recorded to confirm response accuracy and performance.

Outcome measures

Dependant variables included three measures of cognitive performance: (1) response reaction time; (2) cognitive dual task cost; and (3) cognitive response errors.

Response reaction time: Response reaction time measured the speed with which participants reacted to the visual stimuli presented within the visual interference task. Verbal response reaction times were calculated by subtracting the onset of verbal response to a given word stimulus from the onset of the visual stimulus presentation. The onset of the first visual stimulus of a given trial was configured to appear 1.5 seconds after the final beep of the visual and auditory countdown leading into the task, while the interval between consecutive word stimuli during the trial was set to 1 second. As the onset of visual stimuli presentation was standardized across trials, once the verbal response time to a given stimulus was known, the differential between the two could be calculated, indicating reaction time. A custom Matlab 7.7.0.471 (The MathWorks, USA) program was used to calculate reaction time across trials. Response reaction time was used to calculate dual task cost (see below) across all conditions and is only directly reported specific to baseline (static) visual interference task performance in order to differentiate cognitive performance by concussed participants compared to the non-injured control group in the absence of concurrent task performance. Higher response reaction time values indicate poorer cognitive performance.

Dual task cost: Dual task cost (DTC) measured decrements in cognitive performance by comparing cognitive performance while completing concurrent tasks compared to cognitive performance while completing the visual interference task alone. DTC was calculated by comparing verbal response reaction times to the visual interference task stimuli during concurrent task performance trials to verbal response reaction time for the visual interference task stimuli during the baseline (static) trial using the following equation:

$$\text{DTC\%} = \frac{(\text{Dual Task Response Reaction Time} - \text{Single Task Response Reaction Time})}{\text{Single Task Response Reaction Time}} \times 100$$

As this equation allows dual task costs to be interpreted as a percentage, controlling for variable baseline performance amongst participants and allowing for comparison across individuals is possible [23]. The single task response reaction time value was generated by taking the mean reaction time across verbal responses to each stimulus presented during the baseline (static) trial. The dual task response reaction time was the differential between stimulus onset and verbal response onset for each stimulus presented under a given condition. Individual DTC values were reported for each condition during which the visual interference tasks was completed concurrently with ice hockey specific skills by calculating the mean DTC for each stimulus presented across the three trials for that condition. Higher DTC values indicate poorer cognitive performance.

Response errors: Response errors were calculated by summing the number of errors made when responding to the word stimuli of the visual interference task (modified Stroop task). The visual interference task consisted of the words "red", "green" and "blue" being projected onto the screen in colors either congruent (e.g., word «red» written in red) or incongruent (e.g., word "red" written in blue) with the words lexical meaning, where participants were asked to verbally identify the color in which the word was written in. When responding to the visual stimuli, both incorrect responses and omissions were counted as errors. Response errors were determined by matching verbal responses recorded using a portable voice recorder to the known sequence of visual stimuli presented during a given trial. Further, each trial was video recorded in order to confirm the number of response errors committed. Response errors were reported across all conditions (baseline and concurrent task performance). A higher number of response errors indicates poorer cognitive performance.

Data analysis

Given the small number of participants and the pilot nature of the study, a single case approach to data analysis was used. The cognitive performance (DTC and response errors) for individual participants within the concussion group were compared to the mean performance of non-injured controls using the modified t-test of Crawford and Howell [24]. This method uses the t-distribution (with n-1 degrees of freedom), rather than the standard normal distribution, to estimate the abnormality of an individual's scores and to test if these scores are significantly different than the scores of a control sample. In contrast to the use of z-scores, this method controls the Type 1 error rate regardless of the sample size and is robust to violations of normality [24]. The formula for this test is:

$$t = \frac{X1 - X2}{s\sqrt{(n+1)/n}} \quad (2)$$

Where X_1 is the individual's score, X_2 and s are the mean and standard deviation of scores in the control sample and n is the size of the control sample. These analyses were completed using the 'Singlims ES' computer program (available online: http://homepages.abdn.ac.uk/j.crawford/pages/dept/SingleCaseMethodsComputerPrograms.HTM). The threshold for statistical significance was set at $p \leq 0.05$.

Results

The cognitive performance across all conditions of individual participants within the concussion group, along with mean performance of non-injured controls and results from the modified t-test comparing individual scores to control group scores are presented in Tables 4 (DTC) and 5 (response errors).

Dual task cost results

At baseline (static visual interference task), it was found that no participants in the concussion group performed significantly poorer than non-injured controls (poorer performance indicated by slower response reaction time) and Participant 2 performed significantly better (faster response reaction time) than non-injured controls (t(9)=-3.051, p=0.007). During concurrent task performance, both Participant 1 (44 days post-concussion) and Participant 2 (58 days post-concussion) demonstrated significantly poorer performance (increased DTC) when compared to non-injured controls across conditions. Participant 1 demonstrated significantly poorer performance during conditions involving: visual interference task+skating (t(9)=2.292, p=0.024); visual interference task+skating+stickhandling (t(9)=3.232, p=0.005); visual interference task+skating+stickhandling+obstacle avoidance to the right (t(9)=2.305, p=0.023); and, across all conditions collapsed (t(9)=1.824, p=0.050). Participant 2 demonstrated significantly poorer performance during conditions involving: visual interference task+skating+stickhandling (t(9)=2.052, p=0.035); visual interference task+skating+stickhandling+obstacle avoidance to the right (t(9)=1.907, p=0.045); and, across all conditions collapsed (t(9)=1.823, p=0.050). Participant 3 (123 days post-concussion) and Participant 4 (145 days post-concussion) did not demonstrate poorer performance when compared to non-injured controls during any conditions or across all conditions collapsed.

Response error results

At baseline (static visual interference task), it was found that no participants in the concussion group performed significantly poorer than non-injured controls (poorer performance indicated by increased response errors). During concurrent task performance, Participant 1 (44 days post-concussion), Participant 2 (58 days post-concussion) and Participant 3 (123 days post-concussion) demonstrated significantly poorer performance (increased response errors) when compared to non-injured controls. Participant 1 demonstrated significantly poorer performance during conditions involving: visual interference task+skating+stickhandling (t(9)=2.860, p=0.009). Participant 2 and Participant 3 demonstrated significantly poorer performance during conditions involving: visual interference task+skating (Participant 2: t(9)=6.039, p=0.0001; Participant 3: t(9)=2.860, p=0.009). Participant 4 (145 days post-concussion) did not demonstrate significantly poorer performance when compared to non-injured controls during any conditions and no concussed participants demonstrated significantly poorer performance across all conditions collapsed [Table 5].

Discussion

This single case pilot study was conducted to act as an initial step towards a greater understanding of the influence of concussion on

Condition	Non-injured controls (n=10)	Concussed participants (n=4)	Significance (one-tailed probability)
Baseline (RRT, s)	0.85 (SD: 0.10)	Participant 1: 0.89	t(9)=0.381, p=0.356
		Participant 2: 0.53**	t(9)=-3.051, p=0.007
		Participant 3: 0.80	t(9)=-0.477, p=0.322
		Participant 4: 0.70	t(9)=-1.430, p=0.093
VI+S (DTC, %)	-15.6 (SD: 18.3)	Participant 1: 28.4*	t(9)=2.292, p=0.024
		Participant 2: 14.6	t(9)=1.573, p=0.075
		Participant 3: -6.7	t(9)=0.464, p=0.327
		Participant 4: -25.8	t(9)=-0.531, p=0.304
VI+S+SH (DTC, %)	-11.7 (SD: 11.8)	Participant 1: 28.3**	t(9)=3.232, p=0.005
		Participant 2: 13.7*	t(9)=2.052, p=0.035
		Participant 3: 6.1	t(9)=1.438, p=0.092
		Participant 4: -19.5	t(9)=-0.630, p=0.272
VI+S+OR (DTC, %)	-13.1 (SD: 16.3)	Participant 1: -8.3	t(9)=0.281, p=0.393
		Participant 2: 11.9	t(9)=1.462, p=0.089
		Participant 3: -9.0	t(9)=0.240, p=0.408
		Participant 4: -35.9	t(9)=-1.334, p=0.108
VI+S+SH+OR (DTC, %)	-6.4 (SD: 17.5)	Participant 1: 35.9*	t(9)=2.305, p=0.023
		Participant 2: 28.6*	t(9)=1.907, p=0.045
		Participant 3: -4.8	t(9)=0.087, p=0.466
		Participant 4: -20.1	t(9)=-0.746, p=0.237
VI+S+OL (DTC, %)	-9.8 (SD: 18.0)	Participant 1: -0.1	t(9)=0.514, p=0.310
		Participant 2: 19.6	t(9)=1.577, p=0.077
		Participant 3: -14.5	t(9)=-0.249, p=0.405
		Participant 4: -35.2	t(9)=-1.345, p=0.106
VI+S+SH+OL (DTC, %)	-11.4 (SD: 16.6)	Participant 1: 17.6	t(9)=1.666, p=0.065
		Participant 2: 0.3	t(9)=0.672, p=0.259
		Participant 3: -1.9	t(9)=0.546, p=0.299
		Participant 4: -33.1	t(9)=-1.246, p=0.122
Total (all conditions) (DTC, %)	-10.9 (SD: 12.7)	Participant 1: 13.4*	t(9)=1.824, p=0.050
		Participant 2: 13.5*	t(9)=1.823, p=0.050
		Participant 3: -4.6	t(9)=0.473, p=0.324
		Participant 4: -25.9	t(9)=-1.126, p=0.145

*Significant difference (p ≤ 0.05)
**Significant difference (p ≤ 0.01)
Abbreviations: VI: Visual Interference Task; S: Skating; SH: Stickhandling; OR: Obstacle Avoidance to the Right; OL: Obstacle Avoidance to the Left; SD: Standard Deviation; RRT: Response Reaction Time; DTC: Dual Task Cost

Table 4: Cognitive performance (DTC) of concussed participants compared to non-injured controls.

Condition	Non-injured controls (n=10)	Concussed participants (n=4)	Significance (one-tailed probability)
Baseline (errors, n)	0.2 (SD: 0.4)	Participant 1: 0	t(9)=-0.477, p=0.323
		Participant 2: 0	t(9)=-0.477, p=0.323
		Participant 3: 0	t(9)=-0.477, p=0.322
		Participant 4: 0	t(9)=-0.477, p=0.323
VI+S (errors, n)	0.1 (SD: 0.3)	Participant 1: 0	t(9)=-0.318, p=0.379
		Participant 2: 2*	t(9)=6.039, p=0.0001
		Participant 3: 1*	t(9)=2.860, p=0.009
		Participant 4: 0	t(9)=-0.318, p=0.379
VI+S+SH (errors, n)	0.2 (SD: 0.6)	Participant 1: 2*	t(9)=2.860, p=0.009
		Participant 2: 0	t(9)=-0.318, p=0.379
		Participant 3: 0	t(9)=-0.318, p=0.379
		Participant 4: 0	t(9)=-0.318, p=0.379
VI+S+OR (errors, n)	0.7 (SD: 1.3)	Participant 1: 2	t(9)=0.953, p=0.183
		Participant 2: 0	t(9)=-0.513, p=0.310
		Participant 3: 1	t(9)=0.220, p=0.415
		Participant 4: 0	t(9)=-0.513, p=0.310
VI+S+SH+OR (errors, n)	0.2 (SD: 0.6)	Participant 1: 1	t(9)=1.271, p=0.118
		Participant 2: 0	t(9)=-0.318, p=0.379
		Participant 3: 0	t(9)=-0.318, p=0.379
		Participant 4: 0	t(9)=-0.318, p=0.379
VI+S+OL (Errors, n)	0.6 (SD: 1.3)	Participant 1: 0	t(9)=-0.440, p=0.335
		Participant 2: 1	t(9)=0.293, p=0.389
		Participant 3: 0	t(9)=-0.440, p=0.335
		Participant 4: 0	t(9)=-0.440, p=0.335
VI+S+SH+OL (errors, n)	0.7 (SD: 1.1)	Participant 1: 0	t(9)=-0.607, p=0.280
		Participant 2: 0	t(9)=-0.607, p=0.280
		Participant 3: 0	t(9)=-0.607, p=0.280
		Participant 4: 0	t(9)=-0.607, p=0.280
Total (all conditions) (errors, n)	2.7 (SD: 3.4)	Participant 1: 5	t(9)=0.645, p=0.268
		Participant 2: 3	t(9)=0.084, p=0.467
		Participant 3: 2	t(9)=-0.196, p=0.424
		Participant 4: 0	t(9)=-0.757, p=0.234

*Significant difference (p ≤ 0.01)
Abbreviations: VI: Visual Interference Task; S: Skating; SH: Stickhandling; OR: Obstacle Avoidance to the Right; OL: Obstacle Avoidance to the Left; SD: Standard Deviation; n: Number

Table 5: Cognitive performance (response errors) of concussed participants compared to non-injured controls.

dual task cognitive performance in youth ice hockey players and to inform further study and development of sport-specific measures of readiness to return to play. To our knowledge, this study shows for the first time the use of an ice hockey specific assessment protocol to compare cognitive abilities of concussed youth athletes to non-injured controls. Although generally descriptive, findings illustrate differences in cognitive abilities during concurrent ice hockey specific task performance. Specifically, when examining DTC performance, two of the four concussed participants performed significantly poorer than non-injured controls on at least one of the six total conditions of combined visual interference and ice hockey skills, as well as across all conditions collapsed. These concussed participants were significantly slower in responding to visual stimuli despite equivalent accuracy when required to do two or more things at once. These findings support results reported in previous studies examining the influence of combined locomotor and cognitive task performance on cognitive outcomes in athletes following concussion [16,18,25-27] however, the current study demonstrates this influence in youth athletes for the first time.

When considering response errors during concurrent task performance, fewer differences between concussed individuals and non-injured controls were found. Here, there were only three instances across conditions where concussed participants performed significantly poorer than non-injured controls, compared to the six instances for DTC. Further, when considering all conditions collapsed, no concussed participants demonstrated significantly more total response errors than non-injured controls, compared to two of the four concussed participants who demonstrated significantly greater total DTC than non-injured controls. Halterman et al. [26] found a similar contrast in cognitive performance results when examining reaction time and response accuracy on a visuospatial task, reporting significantly slower reaction times in concussed athletes compared to healthy controls, however no difference between groups specific to response accuracy. It is possible that measures of reaction time, such as that used to calculate DTC within the current study, can be considered more sensitive than measures of response errors, where this increased sensitivity allows for the recognition of post-concussion performance deficits. This finding of increased sensitivity to impairment when using measures of cognition that are reaction time-based compared to response accuracy-based can be used to inform which measures are most appropriate to include within further study and during clinical situations when assessing post-concussion cognitive performance as a means to inform recovery and return to play decisions.

Influence of condition on cognitive performance

This study found that the performance of some conditions during the study protocol resulted in significant deficits in cognitive performance amongst concussed participants, while others did not. Performance during the most complex combination of concurrent tasks (4 tasks: visual interference task+skating+stickhandling+obstacle avoidance right), resulted in the greatest amount of relative DTC across participants (Participant 1: 35.9%; Participant 2: 28.6%), where this performance was considered significantly poorer than non-injured controls (Participant 1: $t(9)=2.305$, $p=0.023$; Participant 2: $t(9)=1.907$, $p=0.045$). These findings are consistent with previous study of concussed adults during the performance of combined cognitive and locomotor tasks, where increased task complexity resulted in greater dual task costs [17]. Participating in competitive ice hockey requires constant performance of concurrent tasks (e.g., skating, stickhandling, avoiding opponents, responding to visual cues etc.). If cognitive abilities are impaired during the performance of concurrent sport-specific skills, this could leave youth ice hockey players vulnerable to repeated injury and concussion.

During the completion of the most complex combination of concurrent tasks, it is interesting to note that a significant influence when comparing concussed participants to non-injured controls was only found during obstacle avoidance to the right side and not to the left. Why the side of circumvention resulted in different effects on DTC is unclear at this point. When using an identical protocol to examine the influence of completing tasks of increased complexity on cognitive performance in healthy youth ice hockey players, Fait et al. [20] also found that participants demonstrated significantly greater DTC during the most complex experimental condition and only when avoiding the obstacle to the right side. One possible explanation put forth by Fait et al. [20] was related to the side of the body that participants stickhandle most comfortably on, where increased comfort related to stickhandling side may result in less cognitive resources required to avoid an obstacle on that side leading to the potential for lower levels of DTC. In their study, seven of eight healthy youth ice hockey players stickhandled most comfortably on the left side. Related to the current study, Participant 1 stickhandled on the right side and Participant 2 stickhandled on the left side. Further exploration of the influence of which side youth ice hockey players stickhandle most comfortably on and DTC during obstacle circumvention is warranted.

Although the largest DTC were found during the completion of conditions of the greatest complexity, significant performance deficits related to DTC and response errors when comparing concussed participants to non-injured controls were also found during the completion of conditions of lesser complexity. These findings suggest that completing concurrent cognitive and motor tasks can discriminate performance between concussed participants and non-injured controls, despite a lower level of task complexity. From a clinical perspective, these findings suggest the need to develop improved assessment protocols for youth following concussion and emphasize the value in assessing concurrent task performance at different levels of complexity.

Influence of time since injury on cognitive performance

Descriptively, time since injury (days post-concussion) appeared to influence the cognitive abilities of concussed athletes during concurrent task performance. Specific to DTC, the greatest dual task costs for each condition and all conditions collapsed were demonstrated by the participants who sustained their concussions most recently (Participant 1, 44 days post-concussion; and, Participant 2, 58 days post-concussion). Further, these participants were the most likely to perform worse than non-injured controls, demonstrating significantly higher DTC scores on three of six conditions for Participant 1 and two of six conditions for Participant 2, as well as for all conditions collapsed. What is most intriguing about these findings is that although these participants were a considerable time post injury (44 and 58 days), were no longer reporting post-concussion symptoms, and did not perform significantly poorer than non-injured controls on isolated cognitive assessment (baseline/static visual interference task), they demonstrated significant deficits in reaction time during sport-specific task performance. Although traditional and internationally recognized post-concussion rehabilitation protocols and recommendations [1,7] would view these participants as ready to return to play (no post-concussion symptoms, no deficits on isolated cognitive assessment), it is clear that based on the assessment of cognitive abilities during real-world and sport-specific task performance, further training and rehabilitation may be required.

Using the most extreme case as an example, during concurrent visual interference task performance, skating, stickhandling and obstacle circumvention to the right (most complex of conditions), concussed participants 1 (44 days post-concussion) and 2 (58 days post-concussion) respectively reacted to visual stimuli 36% and 29% slower than when reacting to the same visual stimuli in the absence of concurrent task performance. Functionally, related to ice hockey participation, this slowed ability to respond to visual stimuli (e.g., an opponent) may result in a greater risk to be involved in an injurious situation (e.g., body contact from an opponent) and the potential for a secondary concussive event. The uncovering of residual deficits following concussion, despite being considered fully recovered, is supported by previous laboratory-based study where concurrent cognitive and motor tasks were assessed in concussed young adult elite athletes [16,18]. Together, these findings support the notion of using a more ecologically valid assessment of performance in order to determine readiness to return to play following concussion.

Study limitations

The small sample size of this study can be considered a limitation, only allowing for limited descriptive report of cognitive performance between four concussed individuals and a small non-injured control group. Further study involving larger numbers of concussed and non-injured athletes is needed in order to support the current findings and to further explore the use of concurrent and sport-specific task performance when assessing outcomes following concussion in this population. Despite this small sample size, it is important to present the first preliminary descriptive data in a cohort never before considered (youth ice hockey players). Although overall differences in cognitive performance (DTC) were found between non-injured controls and concussed participants up to 58 days post-injury, the length of time post-injury for the concussed participants involved in this study can be considered a limitation. It is possible that additional cognitive performance deficits would have been found in athletes who had experienced more recent concussions and further insight into the influence of time since injury on task performance could have been obtained.

The potential influence of participant skill level could be viewed as a limitation to this study. Although participants were included within the study according to the competition level for which their ice hockey team participated at (either A or AA) in order to examine participants of similar ice hockey playing ability, great variability in skill level amongst participants may still have existed. Capacity theories are often considered the dominant cause of dual task costs during concurrent task performance [18], where decreased performance is due to competition between tasks for a finite pool of cognitive resources [27]. It has been argued that the more automatic task completion is, the less cognitive resources are needed to perform this task and the less influence this task performance will have on potential dual task costs [13]. It is possible that in more skilled youth ice hockey players, performing ice hockey related tasks may be more automatic and thus, less likely to influence dual tasks costs specific to cognitive performance. Future study could use additional measures of baseline ice hockey skill performance (e.g., skating ability, stickhandling skills etc.) as a means to categorize participants according to skill level and further explore the influence of ice hockey skills on concurrent task performance.

Conclusion

Participation in the sport of ice hockey can be considered highly cerebral in order to process and respond to multiple concurrent stimuli at high speeds. Deficits in the capacity to respond due to a concussion will affect the ability to avoid potentially injurious situations (e.g. body contact from an opponent), putting youth ice hockey players at risk for repeated, and more serious, brain injury. This pilot single-case descriptive study demonstrated that despite being up to 58 days post-concussion, reporting no post-concussion symptoms and performing at a comparable level to non-injured controls on an isolated assessment of cognitive performance, when performing concurrent ice hockey specific tasks, concussed youth ice hockey players demonstrated deficits in dual-tasking abilities. The findings presented within this study support the need for further research exploring the use of ecologically valid and sport specific assessment protocols to provide a more accurate index of readiness to return to play following concussion; however confirmation using larger group-based research studies is required.

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References

1. McCrory P, Meeuwisse WH, Aubry M, Cantu B, Dvorák J, et al. (2013) Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. Br J Sports Med 47: 250-258.
2. Langlois JA, Rutland-Brown W, Wald MM (2006) The epidemiology and impact of traumatic brain injury: a brief overview. J Head Trauma Rehabil 21: 375-378.
3. Powell JW (2001) Cerebral Concussion: Causes, Effects, and Risks in Sports. J Athl Train 36: 307-311.
4. Emery CA, Meeuwisse WH (2006) Injury rates, risk factors, and mechanisms of injury in minor hockey. Am J Sports Med 34: 1960-1969.
5. Williamson IJ, Goodman D (2006) Converging evidence for the under-reporting of concussions in youth ice hockey. Br J Sports Med 40: 128-132.
6. McCrory P, Meeuwisse W, Johnston K, Dvorak J, Aubry M, et al. (2009) Consensus statement on Concussion in Sport 3rd International Conference on Concussion in Sport held in Zurich, November 2008. Clin J Sport Med 19: 185-200.
7. Cantu RC (1998) Second-impact syndrome. Clin Sports Med 17: 37-44.
8. McCrory P, Davis G, Makdissi M (2012) Second impact syndrome or cerebral swelling after sporting head injury. Curr Sports Med Rep 11: 21-23.
9. Covassin T, Elbin RJ, Nakayama Y (2010) Tracking neurocognitive performance following concussion in high school athletes. Phys Sportsmed 38: 87-93.
10. Collie A, Makdissi M, Maruff P, Bennell K, McCrory P (2006) Cognition in the days following concussion: comparison of symptomatic versus asymptomatic athletes. J Neurol Neurosurg Psychiatry 77: 241-245.
11. Echemendia RJ, Cantu RC (2003) Return to play following sports-related mild traumatic brain injury: the role for neuropsychology. Appl Neuropsychol 10: 48-55.
12. McCrory P, Johnston K, Meeuwisse W, Aubry M, Cantu R, et al. (2005) Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. Br J Sports Med 39: 196-204.
13. Haggard P, Cockburn J, Cock J, Fordham C, Wade D (2000) Interference between gait and cognitive tasks in a rehabilitating neurological population. J Neurol Neurosurg Psychiatry 69: 479-486.
14. Huang HJ, Mercer VS (2001) Dual-task methodology: applications in studies of cognitive and motor performance in adults and children. Pediatr Phys Ther 13: 133-140.
15. Fait P, McFadyen BJ, Swaine B, Cantin JF (2009) Alterations to locomotor navigation in a complex environment at 7 and 30 days following a concussion in an elite athlete. Brain Inj 23: 362-369.
16. Parker TM, Osternig LR, van Donkelaar P, Chou LS (2007) Recovery of cognitive and dynamic motor function following concussion. Br J Sports Med 41: 868-873.
17. Fait P, Swaine B, Cantin JF, Leblond J, McFadyen BJ (2013) Altered integrated locomotor and cognitive function in elite athletes 30 days postconcussion: a preliminary study. J Head Trauma Rehabil 28: 293-301.
18. Abernathy B (1988) Dual-task methodology and motor skills research: some applications and methodological constraints. J Hum Mov Stud 14: 101-132.
19. Mann DT, Williams AM, Ward P, Janelle CM (2007) Perceptual-cognitive expertise in sport: a meta-analysis. J Sport Exerc Psychol 29: 457-478.
20. Fait PE, McFadyen BJ, Zabjek K, Reed N, Taha T, et al. (2011) Increasing task complexity and ice hockey skills of youth athletes. Percept Mot Skills 112: 29-43.
21. Golden CJ (1978) Stroop Color and Word Test: A Manual for Clinical and Experimental Uses. Skoelting, Chicago, IL, USA.
22. Gérin-Lajoie M, Ronsky JL, Loitz-Ramage B, Robu I, Richards CL, et al. (2007) Navigational strategies during fast walking: a comparison between trained athletes and non-athletes. Gait Posture 26: 539-545.
23. McCulloch K (2007) Attention and dual-task conditions: physical therapy implications for individuals with acquired brain injury. J Neurol Phys Ther 31: 104-118.
24. Crawford J, Howell D (1998) Comparing an individual's test score against norms derived from small samples. Clin Neuropsychol 12: 482-486.
25. Catena RD, van Donkelaar P, Chou LS (2011) The effects of attention capacity on dynamic balance control following concussion. J Neuroeng Rehabil 8: 8.
26. Halterman CI, Langan J, Drew A, Rodriguez E, Osternig LR, et al. (2006) Tracking the recovery of visuospatial attention deficits in mild traumatic brain injury. Brain 129: 747-753.
27. Maki BE, McIlroy WE (2007) Cognitive demands and cortical control of human balance-recovery reactions. J Neural Transm 114: 1279-1296.

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