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INCREASING TASK COMPLEXITY AND ICE HOCKEY SKILLS OF YOUTH ATHLETES[1,2]

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Summary.—The objective of this pilot study was to investigate the effects on cognitive performance of progressively adding tasks specific to ice hockey (skating, stick handling, and obstacle avoidance) during a visual interference task (Stroop Color Word Test–interference condition). In addition, the effects on locomotor performance of progressively adding tasks of stickhandling, visual interference, and obstacle avoidance related to maximal skating speed and minimal obstacle clearance were investigated in eight male athletes ages 10 to 12 years. Results revealed decreased performance on both cognitive and physical measures with increased task complexity, suggesting that adding complexity to an environment influences hockey skill performance.

The sport of ice hockey requires the integration of multiple skills (i.e., performing the locomotor task of skating while trying to direct a pass, shoot a goal, and/or avoid a body check) for successful performance and for safety (i.e., avoiding collision and injury). Ice hockey skills have rarely been subject to experimental manipulation (Leavitt, 1979), thus the information processing demands associated with the integration of cognitive and locomotor skills in this sport context are poorly understood. Dual-

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task paradigms provide an experimental method where the effect of increasing task complexity on information processing load can be observed via performance decrements on one or more tasks. The present study adapted dual-task protocols used to examine locomotor navigation while walking over the ground (e.g., Gérin-Lajoie, Richards, & McFadyen, 2005) to skating on the ice.

As outlined by Abernathy (1988), the dual-task methodology examines two tasks performed simultaneously, with one task designated as the primary task and the other as the secondary task. This paradigm purports that performance on the primary task is to remain at baseline or single-task level (as would be performed in the absence of the secondary task), while reduced performance on the secondary task during the dual-task condition is what denotes an interference effect (Woollacott & Shumway-Cook, 2002; McCulloch, 2007). In the current study, performance on the cognitive task of the Stroop Color Word Test–interference condition (Stroop, 1935) and skating, stick handling, and obstacle avoidance were simultaneously prioritized by asking the athletes to skate as fast as possible and, at the same time, perform the Stroop Color Word Test as fast and accurately as possible. Dual-task cost was the metric used to assess the difference in performance during a dual-task condition compared to a single-task condition (McCulloch, 2007).

In youth populations, most dual-task studies have looked at developmental differences in cognition (Björklund & Gage, 1987; Guttentag, 1988; Miller, Seier, Probert, & Aloise, 1991; Irwin-Chase & Burns, 2000; Karatekin, 2004) and tend to show that as children get older, there is a general decrease in dual-task costs. Studies of typically developing children have demonstrated age-related differences between children and young adults with respect to dual-task prioritization, where children place greater priority on balance stability versus cognitive tasks in dual-task conditions (Schaefer, Krampe, Lindenberger, & Baltes, 2008). Irwin-Chase and Burns (2000) also found developmental changes in children's dual-task performances when tasks were assigned different priorities. In this case, only older children (*M* age = 11.1 yr.) were able to allocate attention differentially during a dual task.

Studies examining the effects of the dual-task paradigm on children have been traditionally held in laboratory settings (i.e., Huang, Mercer, & Thorpe, 2003; Laufer, Ashkenazi, & Josman, 2008; Schaefer, *et al.*, 2008). However, two studies involving youth athletes have been performed in a sport-specific setting (Leavitt, 1979; Smith & Chamberlin, 1992). Leavitt (1979) analyzed dual-task performance in hockey skills to provide information regarding the cognitive demands of ice hockey. Leavitt (1979) conducted a series of studies where progressively adding the secondary tasks of stick handling a puck and visual interference produced little effect on the primary task of skating speed in experienced hockey players, but significantly slowed skating speed in novice hockey players. A more recent study by Smith and Chamberlain (1992) sought to examine whether similar results could be found in the sport of soccer, in which running and dribbling a ball are performed by the same limbs (compared to hockey where stick handling and skating are performed by separate limbs), where the dual-task cost is hypothesized to be greater (Smith & Chamberlin, 1992). Their results revealed that the addition of cognitively demanding elements caused a decrement in performance, but the decrement was reduced with increased expertise.

These two studies are unique with respect to the measurement of dual-task performance in a sport-specific environment. While Leavitt (1979) did combine the skills of skating, stick handling, and visual interference (which required the players to skate with their heads up—a skill emphasized to prevent injury), he did not include obstacle avoidance, a fourth skill which is arguably necessary for successful hockey performance to avoid intentional body checks from opposing players and incidental contact with opponents, teammates, referees, and objects on the playing surface (e.g., hockey nets, etc.). In addition, neither study examined biomechanical measures associated with sport performance (i.e., minimum distance to obstacle clearance). Given the paucity of information regarding dual-task performance in sport-specific environments, particularly in youth, the current study was designed to investigate the effects of progressively adding the ice hockey-specific tasks of skating, stick handling, and obstacle avoidance on cognitive performance during a visual interference task, and to investigate the effects of progressively adding the ice hockey-specific tasks of stick handling, visual interference and obstacle avoidance on maximal skating speed and minimal obstacle clearance in youth athletes ages 10 to 12 years. It was hypothesized that cognitive performance (as measured by accuracy and dual-task cost on the Stroop Color Word Test–interference condition) would be negatively affected by the introduction of each secondary physical task compared to baseline (i.e., single-task performance). Likewise, it was hypothesized that maximal skating speed and minimal obstacle clearance (measured in metres per second and metres, respectively) would be negatively affected by the introduction of each secondary task compared to baseline.

Method

Participants

A convenience sample of eight competitive youth male ice hockey players (*M* age=11.25 yr., *SD*=0.90) from the Greater Toronto Hockey League (minor Peewee AA and Peewee AA) and the Mississauga Hockey

League (Minor Peewee A) was recruited. Representative level ice hockey teams participate in three divisions based on skill. These divisions are A, AA, and AAA, where A represents the lowest skill and AAA represents the highest skill. 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 youth ice hockey player. Participants' characteristics are shown in Table 1. 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 the youth participants and their assent was obtained in order to proceed with the study protocol. Exclusion criteria included any self-reported neurological or musculoskeletal problems or taking medication affecting alertness or locomotion. The participants wore their own helmets, skates, gloves, and a comfortable full track suit. They also used their own hockey sticks.

TABLE 1
PARTICIPANTS' CHARACTERISTICS ($N = 8$ MALES)

Participant	Age (yr.)	Height (m)	Weight (kg)	Stick Handling Side Preference
SK005	10	1.45	44.3	Left
SK006	11	1.50	31.8	Left
SK007	12	1.62	62.9	Left
SK008	10	1.35	32.7	Left
SK009	12	1.50	38.5	Left
SK010	12	1.75	72.3	Right
SK011	12	1.64	50.5	Left
SK012	11	1.42	40.9	Left
M	11.25	1.53	46.74	
SD	0.89	0.13	14.43	

Task Protocol

The protocol was designed to increase task complexity in a stepwise fashion to replicate the increasing attentional and physical demands present in a complex, real-world ice hockey competition. Participants had to perform three trials for each of the 12 conditions representing four levels of complexity (Level 1 = lowest complexity to Level 4 = highest complexity) presented in a randomized fashion. The task protocol conditions, along with corresponding complexity, are presented in Table 2. All participants were allowed to practice the Stroop task ahead of time and to perform each condition (with and without obstacle, with and without dual task, with and without stick handling) before data collection began. These practice trials were performed prior to the protocol and after the youth athletes had completed a warm-up consisting of light skating and stretching of large muscle groups.

TABLE 2
TASK PROTOCOL CONDITIONS

Complexity	Skating	Stroop-word Task	Obstacle Avoidance (left and right)	Stick Handling
1	✓			
		✓		
2	✓	✓		
	✓		✓	
	✓			✓
3	✓	✓	✓	
	✓	✓		✓
	✓		✓	✓
4	✓	✓	✓	✓

Note.—Three trials completed per condition.

Description of Tasks

Skating.—This locomotor task consisted of skating along a 16.5-m path (see Fig. 1). The athlete was instructed to skate as fast as possible without stopping from a starting location marked on the ice to an ice hockey net located straight ahead. Full speed skating was used to target a specific locomotor behavior of ice hockey players and to reduce variability in performance observed during pilot work associated with instructions to skate at a comfortable pace.

Visual interference.—The Stroop Color Word Test–interference condition (Stroop, 1935) was used on half of the trials and the youth athletes were informed in advance of its presence in the trial. During the Interference Condition, the words "red," "green," and "blue" were projected using PowerPoint 2007 (Microsoft Corporation, USA) with a data projector (Epson Powerlite 77c) set 2.83 m from the screen on a table that was 0.90 m in height. The onset of the visual stimulus was indicated via a visual and auditory countdown prior to the beginning of the trial. During this countdown the numbers 3, 2, 1 followed by the signal "Go!" would each appear 500 msec. apart paired with a beep. Athletes would start skating as fast as possible at the presentation of "Go!" and 500 msec. after the "Go!" signal appeared on the screen, the first Stroop stimulus would appear. The words were projected at a rate of 1 Hz in different congruent or incongruent colors and required the participant to indicate the color of the word while ignoring its lexical meaning. A screen (1.52 m × 1.35 m) was placed in front of the participant at the end of the path. The participants were asked to identify the colors as fast as possible, and their verbal responses were recorded on a voice recorder (Panasonic RR-U360) worn by the participant. Recorded verbal responses were then processed using a custom Matlab 7.7.0.471 (The MathWorks, USA) program. Verbal response reaction time was calculated by subtracting the onset of verbal response from the time of the onset of the visual stimuli. The onset of the visual stimulus could be differentiated from the verbal response because the first visual stimulus always appeared 1.5 sec. after the last beep of the visual and auditory countdown leading into the task and the interstimulus interval was 500 msec., allowing accurate calculation of all visual stimulus onset times. All of the trials were videotaped to identify any errors or no response during the performance of the Stroop task.

Obstacle avoidance.—During obstructed trials, participants circumvented a cylindrical obstacle set within the skating path at 8.40 m from the youth athletes' starting location. 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 it upright. A similar obstacle has been used with adult athletes in a previous study (Gérin-Lajoie, Ronsky, Loitz-Ramage, Robu, Richards, & McFadyen, 2007). For all obstructed trials, the athletes were instructed as to the side of the obstacle they had to circumvent (i.e., left or right). No other instructions were given to the athletes about how to perform the skating tasks. An equivalent spacing was provided on either side of the obstacle to allow a symmetric clearance area (see Fig. 1).

Stick handling.—The participants were asked to carry a standard black

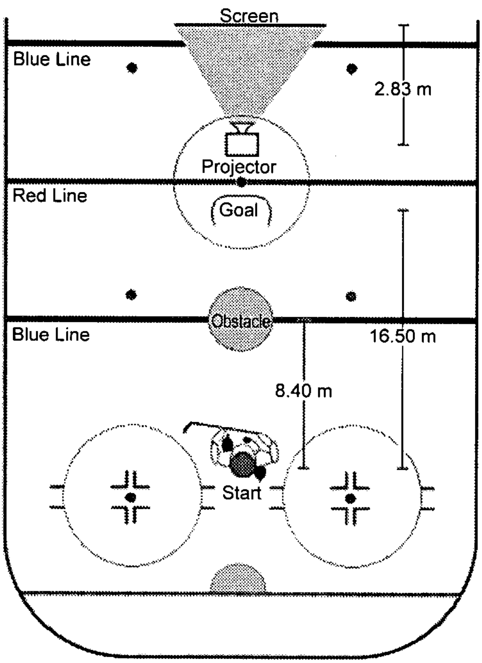

FIG. 1. Experimental setup

ice hockey puck (2.5 cm thick, 7.6 cm in diameter, 0.170 kg) with an ice hockey stick from the start location to the net set at the end of the path. All participants used their own ice hockey stick for the experiment.

Apparatus

Three-dimensional kinematic data during skating were collected at a frequency of 50 Hz with a motion analysis system (Vicon Mx Ultranet HD with 3 MX-3+ Cameras, USA) and using markers that were fixed on the participants' feet (on the heel of the skates), trunk (at C7 level), shoulders, and on the back of their helmets. Other measures included participants' height and weight. The kinematic data were interpolated and low-pass filtered at 6 Hz with a second-order double pass Butterworth filter.

Outcome Measures

Dependent variables included measures of cognitive and locomotor performance across varying levels of complexity. Cognitive outcome measures included the number of errors (omissions or wrong answers) on the Stroop Color Word Test–interference condition as well as the dual-task cost associated with reaction time (RT). RTs to the Stroop task during skating were converted to dual-task cost by subtracting out the response RTs while performing the Stroop task alone (Level 1 task complexity; i.e., with no skating, stick handling, or obstacle avoidance) from each condition under subsequent levels of complexity and averaged across trials within that condition. Physical outcome measures included maximum skating speed in meters per second as well as minimum object clearance in meters across all relevant conditions and levels of task complexity. An average for each dependent variable was calculated using custom Matlab 7.7.0.471 (The MathWorks, USA) programs across trials for each participant.

Analysis

Given the small number of participants, a nonparametric statistical test (Friedman's test) was applied to examine repeated effects of increasing task complexity across participants. Four separate Friedman's tests were performed using SPSS Version 17.0 with condition as the independent variable and Stroop task errors, dual-task cost, maximal skating speed, and minimal obstacle clearance as the dependent variables, respectively. Effect size statistics for the Friedman's tests were generated using Kendall's coefficient of concordance (Kendall's W). The coefficient of concordance ranges from 0 to 1, with higher values indicating a stronger relationship. *Post hoc* analyses were completed using nonparametric Wilcoxon tests to determine what contrasts were significant at $p < .05$. Wilcoxon tests were limited to comparing each condition at subsequent levels of task complexity to the lowest level of task complexity for that dependent variable in order to limit the number of multiple comparisons.

Results

Cognitive Results

Stroop task errors.—The frequency of Stroop task errors across all conditions and levels of task complexity are presented in Table 3. Overall, a total of 29 errors were made by five athletes. Friedman's analysis did not indicate a significant effect of experimental task condition on number of Stroop task errors [χ^2_r (6) = 9.86, p = .13, effect size = 0.21]. However, visual inspection of the Stroop task errors revealed that 26 of the 29 errors were recorded when an obstacle was present compared to one error recorded when no obstacle was present and two errors recorded during baseline (i.e., Stroop alone). With respect to side of circumvention, 14 errors were recorded during left-side obstacle circumvention and 12 errors were recorded during right-side obstacle circumvention. To further explore the effect of obstacle circumvention on Stroop task errors, a subsequent Friedman's test was performed with Stroop task errors collapsed across obstacle circumvention conditions (e.g., no obstacle, left-side obstacle circumvention, and right-side obstacle circumvention). The Friedman's test was significant [χ^2_r (2) = 7.41, p = .025, effect size = 0.46]. *Post hoc* Wilcoxon tests revealed that significantly more Stroop errors were made for the no-obstacle versus left-obstacle conditions (Z = −2.07, p = .038), with no significant difference for the no-obstacle versus right-obstacle conditions (Z = −1.84, p = .066) and for the left- versus right-obstacle conditions (Z = −0.272, p = .785).

TABLE 3
DESCRIPTIVE STATISTICS FOR DUAL-TASK COSTS COLLAPSED ACROSS TRIALS FOR EACH EXPERIMENTAL CONDITION

Task Complexity	*N*	*M*	*SE*	*SD*	Range	Min.	Max.
Level 1							
Stroop alone	8	0.81	0.05	0.13	0.41	0.61	1.02
Level 2							
Stroop + Skating	8	−0.08	0.04	0.11	0.28	−0.22	0.06
Level 3							
Stroop + Skating + Stick handling	8	−0.05	0.05	0.14	0.41	−0.23	0.18
Stroop + Skating + Right obstacle	8	−0.06	0.05	0.13	0.34	−0.25	0.10
Stroop + Skating + Left obstacle	8	−0.05	0.04	0.10	0.29	−0.18	0.11
Level 4							
Stroop + Skating + Stick handling + Right obstacle	8	−0.01	0.05	0.13	0.37	−0.25	0.12
Stroop + Skating + Stick handling + Left obstacle	8	−0.12	0.06	0.18	0.57	−0.18	0.39

Dual-task costs.—Descriptive statistics for dual-task cost collapsed across trials for each experimental condition are presented in Table 4.

TABLE 4

DESCRIPTIVE STATISTICS FOR MAXIMAL SKATING SPEED (METRES PER SECOND) COLLAPSED ACROSS TRIALS FOR EACH EXPERIMENTAL CONDITION

Task Complexity	*N*	*M*	*SE*	*SD*	Range	Min.	Max.
Level 1							
Skating only	8	5.41	0.09	0.24	0.69	5.01	5.71
Level 2							
Skating + Stick handling	8	5.22	0.12	0.30	1.09	4.62	5.71
Skating + Stroop	8	5.21	0.11	0.30	0.82	4.67	5.48
Skating + Right obstacle	8	5.11	0.10	0.28	0.91	4.69	5.59
Skating + Left obstacle	8	5.04	0.11	0.32	1.01	4.47	5.47
Level 3							
Skating + Stick handling + Stroop	8	4.99	0.11	0.31	1.03	4.37	5.40
Skating + Right obstacle + Stroop	8	4.87	0.13	0.36	1.01	4.24	5.25
Skating + Left obstacle + Stroop	8	4.86	0.13	0.37	1.06	4.12	5.17
Skating + Right obstacle + Stick handling	8	4.81	0.11	0.30	0.92	4.30	5.21
Skating + Left obstacle + Stick-handling	8	4.76	0.08	0.23	0.54	4.48	5.02
Level 4							
Skating + Right obstacle + Stick handling + Stroop	8	4.52	0.10	0.28	0.75	4.13	4.88
Skating + Left obstacle + Stick handling + Stroop	8	4.51	0.14	0.39	1.13	3.82	4.95

Friedman's test indicated a significant effect of experimental task condition on dual-task cost [X^2_r (6) = 25.13, $p < .001$, effect size = 0.52]. Follow-up analyses using Wilcoxon tests compared the dual-task cost associated with each condition to the dual-task cost associated with the Level 2 task complexity of Stroop task + skating. The Wilcoxon tests revealed a significant difference in dual-task cost for the Level 4 complexity task of Stroop + skating + stick handling + right-obstacle circumvention compared to the dual-task cost associated with Stroop + skating ($Z = -2.38$, $p = .017$).

Locomotor Results

Maximal skating speed.—The descriptive statistics for maximal skating speeds for all experimental conditions are presented in Table 5. Friedman's test revealed a significant effect of experimental task condition on maximal skating speed [χ^2_r (11) = 66.12, $p < .001$, effect size = 0.75]. *Post hoc* Wilcoxon tests compared the maximal skating speed for each condition to the maximal skating speed associated with the Level 1 task complexity of skating alone. The addition of the Stroop task resulted in significantly slower maximal skating speed at Level 2 task complexity ($Z = -2.24$, $p = .025$); Level 3 task complexity (skating + Stroop + stick handling: $Z = -2.38$, $p = .017$; skating + Stroop + left- obstacle circumvention: $Z = -2.52$, $p = .012$; skating + Stroop + right-obstacle circumvention: $Z = -2.52$, $p = .012$); as well as Level 4 task complexity (skating + Stroop + stick handling + right-obstacle circumvention: $Z = -2.52$, $p = .012$; skating +Stroop + stick handling + left-obstacle circumvention: $Z = -2.52$, $p = .012$).

Minimal clearance of obstacles.—The descriptive statistics for the minimal obstacle clearance associated with all relevant experimental conditions are presented in Table 5. Friedman's test revealed a significant effect of experimental condition on minimal clearance [$\chi^2_r(7) = 23.67$, $p = .001$, effect size = 0.42]. *Post hoc* Wilcoxon tests compared the left and right minimal obstacle clearance for each experimental condition to the minimal obstacle clearance recorded for the Level 2 task complexity condition of left-obstacle clearance + skating and right-obstacle clearance + skating, respectively. The addition of the Stroop task at Level 3 task complexity did not result in a significant difference in minimal obstacle clearance for the left ($Z = -1.26$, $p = .208$) or the right side ($Z = -1.54$, $p = .123$), respectively. In comparison, the addition of stick handling at Level 3 task complexity did result in a significantly greater minimal obstacle clearance for both the left ($Z = -2.52$, $p = .012$) and the right ($Z = -2.10$, $p = .036$) sides, respectively. Finally, the addition of both stick handling and Stroop task at Level 4 task complexity also resulted in a significantly greater minimal obstacle clearance for both the left ($Z = -2.52$, $p = .012$) and the right ($Z = -2.52$, $p = .012$) sides, respectively.

TABLE 5

Descriptive Statistics For Minimal Obstacle Clearance (Meters) Collapsed Across Trials For Each Experimental Condition

Task Complexity	Side	*N*	*M*	*SE*	*SD*	Range	Min.	Max.
Level 2								
Skating	Right	8	0.67	0.06	0.18	0.56	0.43	0.98
Skating	Left	8	0.63	0.04	0.12	0.42	0.43	0.85
Level 3								
Skating + Stroop	Right	8	0.74	0.07	0.19	0.55	0.58	1.13
Skating + Stroop	Left	8	0.70	0.05	0.15	0.46	0.44	0.91
Skating + Stick handling	Right	8	0.90	0.08	0.22	0.80	0.56	1.36
Skating + Stick handling	Left	8	0.83	0.05	0.15	0.40	0.65	1.05
Level 4								
Skating + Stick handling + Stroop	Right	8	1.02	0.11	0.31	0.87	0.72	1.56
Skating + Stick handling + Stroop	Left	8	0.83	0.09	0.24	0.83	0.48	1.31

Discussion

The current study was designed to explore the effects of increasing task complexity on both cognitive and physical measures of hockey skill performance in youth athletes. Cognitive performance was measured via a visual interference task (Stroop Color Word Test–interference condition), and physical performance was assessed by measuring maximal skating speed and minimal distance to circumvent an obstacle. It was hypothesized that cognitive performance (as measured by accuracy and dual-task cost on the Stroop Color Word Test–interference condition) would be negatively affected by the introduction of each secondary physical task compared to baseline (i.e., single-task performance). Likewise, it was hypothesized that maximal skating speed and minimal obstacle clearance would be negatively affected by the introduction of each secondary task compared to baseline. The findings relevant to these hypotheses are discussed below.

Cognitive Performance

The results of the study partially support the initial hypotheses that increasing task complexity affects cognitive performance in a hockey-specific environment. The number of errors on the Stroop task was significantly higher when participants were required to circumvent an obstacle on the left side, but not the right side, compared to when there was no obstacle avoidance required. In comparison, the added task of stick handling a puck did not result in a greater number of errors on the Stroop task. This suggests that the hockey skill of stick handling a puck may require less visual feedback than obstacle avoidance, or more simply, that youth hockey players are more practiced at stick handling than stationary obstacle avoidance. The lack of significant difference between right-side obstacle circumvention and no obstacle circumvention may be related to the side of the body on which players stick handle most comfortably. Seven out of eight players reported stick handling on the left side of their body, and it may be the case that they require less visual feedback to go around the obstacle on the right side than the left, which allows them to concentrate more fully on the visual interference task.

With respect to the dual-task cost associated with reaction time during the Stroop task, when compared to skating while performing the Stroop task alone (Level 2 task complexity), participants showed significantly greater dual-task cost only during the most complex experimental condition (Level 4 task complexity) during right-side obstacle circumvention. Together, the findings specific to Stroop errors and dual-task cost suggest poorer cognitive performance during concurrent obstacle circumvention. With respect to cognitive performance, perhaps the participants were exhibiting a speed/accuracy trade-off during obstacle circumvention. For example, it is possible that the participants sacrificed Stroop task response accuracy in order to limit dual-task cost specific to reaction time during left-side obstacle circumvention, while during right-side circumvention, response accuracy (fewer errors) was the priority. In both scenarios, concurrent obstacle circumvention resulted in poorer cognitive performance.

A recent dual-task study examined the effects of a secondary cognitive task on obstacle avoidance in healthy young adults (Siu, Catena, Chou, van Donkelaar, & Woollacott, 2008). Participants were asked to respond to a secondary auditory Stroop task while concurrently crossing an obstacle during gait. It was found that with increased complexity of the locomotor task, incongruent stimuli required longer reaction times. Although the current study differs from the study conducted by Siu, *et al.* (2008) as it did not measure both incongruent and congruent reaction times, the findings of increased locomotor task complexity leading to poorer cognitive performance are comparable. Similar to that discussed by Siu, *et al.* (2008) in relation to healthy young adults, this finding may be a result of youth ice hockey players prioritizing stability during skating over cognitive performance in dual-task situations, where decreased cognitive performance during tasks of increased complexity manifests as both Stroop task errors (left-side obstacle circumvention) and increased dual-task cost (right-side obstacle circumvention).

Locomotor Performance

The locomotor results also partially supported the initial hypotheses. In particular, the addition of the visual interference test resulted in slower maximal skating speed at all levels of task complexity compared to the single task of skating alone, suggesting that hockey-specific locomotor performance is significantly affected by introducing a cognitive dual-task condition. However, the addition of the visual interference condition did not significantly affect minimal obstacle clearance, contrary to the hypotheses. It is interesting to compare these findings to the cognitive performance conditions where Stroop task errors were greater during the left-side obstacle circumvention, and the dual-task cost was significantly increased when required to circumvent to the right side of the obstacle. Taken together, the results suggest that participants were compromising skating speed to maintain cognitive performance on the visual interference task.

General Discussion

The results of the study are intriguing as the original hypotheses were based on the assumption that participants would accommodate increasing task complexity in a step-wise fashion. However, it appears that performance parameters are more dynamic and flexible than originally assumed, and that certain tasks are given priority depending on the combination of skills required. This assignment of priority makes sense given that some tasks are well learned (like skating) and others are less familiar (for example, the Stroop Color Word Test). However, even well-learned tasks appear to be compromised by the introduction of novel information processing demands in complex environments.

The findings cannot be generalized to all youth ice hockey players because in the current study, all participants were experienced male hockey players and had played competitive hockey. It cannot be assumed that female youth hockey players would demonstrate the same pattern of performance decrements under dual-task conditions. Although, to date, very little has been reported with respect to sex differences specific to concurrent locomotor and cognitive dual-task performance, one study reports increased variability during dual-task walking in older men compared to older women (Hollman, Youdas, & Lanzino, 2009). Although this study differs from the current study, both methodologically and with respect to the population of interest, it highlights the potential for sex differences during concurrent locomotor and cognitive task performance. Further examination of potential sex differences on dual-task performance specific to youth and the sport of ice hockey is needed.

In addition, it is possible that less experienced youth may demonstrate greater performance decrements under dual-task conditions. For example, Leavitt (1979) found that the introduction of a visual identification task significantly slowed skating speed in novice hockey players, but not in more experienced hockey players. The difference in results between the Leavitt (1979) study and the current study may be due to task differences associated with a visual identification versus visual interference task. Smith and Chamberlin (1992) also found that the addition of cognitively demanding elements caused a decrement in performance, regardless of level of expertise, but that this decrement in performance was reduced with increased expertise. Regardless of methodological and task differences, the results of decreased cognitive performance with the addition of a sport-specific locomotor task in the current study echoes findings by both Leavitt (1979) and Smith and Chamberlin (1992).

By comparing separate and combined performance of locomotor and cognitive capacities during skating with a simultaneous visual interference task, the present study provides an innovative way for assessment of locomotor function in a sport-specific and ecological environment. Moreover, it can provide information not accessible with more traditional testing which examines cognitive and locomotor performance independent of one another. In particular, the experimental paradigm could be explored for its potential to assess skill by measuring performance under dual-task conditions, and perhaps sport-specific functional impairments following concussion. Individuals (including youth) with concussion are likely to show a more selective impairment on complex motor tests requiring visio-spatial skills or on those that require the use of additional cognitive skills for successful performance (Rourke & Telegdy, 1971; Rourke & Strang, 1978; Francis, Fletcher, & Rourke, 1988) compared to neuropsychological paper-and-pencil tests (Fait, McFadyen, Swaine, & Cantin, 2009). Performance deficits arise when locomotor and cognitive tasks are performed concurrently that may otherwise go unnoticed if assessed in isolation of one another (Parker, Osternig, van Donkelaar, & Chou, 2007). The results of the current study are limited by the small number of participants which reduced the statistical power to detect statistically significant results. Future studies which include a larger number of participants who vary according to age, sex, and skill should be performed to better understand the influence of these variables on sport-specific dual-task performance. In addition, future studies could adapt the experimental paradigm to other sport-specific environments (e.g., football, soccer, lacrosse, etc.).

Conclusion

This experiment was performed to examine the effects of dual-task conditions on ice hockey-specific performance parameters in male youth ice hockey players. The observed differences in cognitive and locomotor performance associated with varying task complexity suggest that certain skills are given priority when competing for attentional resources in the sport of ice hockey. In particular, obstacle avoidance appears to take priority when present, followed by cognitive performance as measured by a visual interference task. This study is unique as it is the first to examine the effect of combined ice hockey skills on sport-specific parameters and highlights the trade-off between physical and cognitive performance under more complex conditions. The findings have implications for sport-specific assessment of combined cognitive and motor skills of healthy athletes and those who have suffered concussion.

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