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Relationships between Executive Functioning and Level of Competition in Ice Hockey

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Abstract

Executive functions (EF) are assumed to play a key role in sports performance. However, few studies have explored how the core components of EF, namely inhibition, updating and shifting, relate to level of competition in ice hockey. General measures of these components were collected, via computerized tests, on male ice hockey players (*n* = 39) playing at different competitive levels across the Swedish series system. Hockey-specific stimuli were also incorporated into tests of executive functioning to investigate whether information processing was influenced by familiarity with domain-specific content. Results from hierarchical multiple regression analyses revealed significant associations between higher competitive level and measures of inhibitoriy control and updating ability, but not with shifting ability. It warrants noting that superior updating performance was related to level of competition only when hockey-specific stimuli were used. Results also showed overall performance differences between general and hockey-adapted tests, as well as associations among EF components, revealing patterns consistent with both shared and distinct variance. These findings indicate that stimulus manipulation can affect task difficulty and sensitivity, underscoring the importance of stimulus selection when adapting general EF tests. While preliminary and cross-sectional, the results suggest that inhibition and updating may be key targets for future longitudinal and sport-specific EF research, with the potential to enhance ecological validity and inform cognitive training in ice hockey.

Keywords: *Executive Functions, Ice hockey, Level of competition, Updating, Inhibition, Shifting*

Participation in competitive sport places demands on athletes' cognitive abilities. In review of extensive research (see Kalén et al., 2021 for review) highly skilled athletes are noted to perform better than lower-skilled athletes on cognitive tests (e.g., decision-making). As such, Executive Functions (EF) have increasingly been the focus of research within sport science (see Furley et al., 2023 for review). The current study aimed to investigate whether core components of executive functions, measured using both general and hockey-specific stimuli, are associated with competitive level among ice hockey players. By adapting validated EF tasks with sport-related content, we also examined whether such modifications influence performance outcomes and improve the sensitivity of the tests. In this way, the study contributes to the ongoing discussion about how general cognitive testing can be made more relevant for applied performance contexts in sports (see e.g., Beavan et al., 2020; Reinhard et al., 2025).

EF are high-level cognitive processes responsible for attention, decision making, and goal-directed behaviour; they guide actions and performance across many domains and are central to task execution in sport (Friedman et al., 2006; Friedman & Miyake, 2017). Although EF have been shown to predict success across numerous sports (Scharfen & Memmert, 2019), there have been questions raised about the assessment of general EF in talent identification. Recent work by Reinhard et al. (2025) highlights that the relationship between general cognitive skills and sport performance may be partly explained by age-related improvements in cognition. Their study among youth football players also suggests that while some general EF measures show modest associations with sport-specific decision-making, tests tailored to the sport context may offer stronger discriminatory power. These findings indicate caution is warranted to avoid an overreliance on general EF tests for talent identification; further, they highlight the value of including age as a covariate in analyses. Further, related research notes that sport type can determine differences in EF across elite athletes (Krenn et al., 2021). Therefore, sport-specific tests of EF are often recommended to advance both research and applied use of EF tests in sport science (Davis et al., 2022). However, developing entirely new sport-specific EF batteries for every sport is resource-intensive and, for some disciplines,

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technically difficult to develop. A pragmatic first step, therefore, could be to employ validated general EF tests to provide an early indication of whether core components of EF are related to competitive success.

The role of both general and specific executive functions has been examined in individual sports as well as in broader team sport categories (e.g., Elferink-Gemser et al., 2018; Chang et al., 2017; Fledderman et al., 2023; Heilmann et al., 2022; Vona et al, 2024), but less attention has been devoted to specific team sports. Research examining EF in specific team sports has predominantly been undertaken within the sport of soccer (e.g., Brimmell et al., 2021; Sakamoto et al., 2018; Vestberg et al., 2017) which has garnered a great deal of media attention likely due to the global popularity, widespread participation, and associated finances surrounding the sport. Authors of the initial high-profile study within professional soccer (Vestberg et al., 2012) reported professional players had higher scores on a standardized measure of general EF in comparison with lower-level players and standardized population norms. However, more recent research has failed to replicate these findings (Beaven et al., 2020b) and wider reviews contend the supporting evidence for the relationship between general cognitive abilities relating to EF and sport performance remains limited (Furley et al., 2023).

Across the range of research examining EF in sport, several theoretical frameworks have been used. One of these is Baddeley's multicomponent model of working memory (Baddeley, 1986), in which the central executive system is proposed to control subsystems in the processing of visual and spatial information. Another common theoretical framework (or model) of EF is proposed by Miyake et al., (2000) and outlines three component abilities. Specifically, inhibition is the ability to suppress prepotent, conflicting responses that may arise in different situations (Morris & Jones, 1990; Miyake et al., 2000). Behavioural inhibition as it relates to sport, pertains to the ability to restrain automatic but inefficient responses within a situation to achieve a successful outcome (Friedman & Miyake, 2004). Another ability is shifting, or switching, which is the capacity to move between different tasks and/or mental states related to a situation (Miyake et al., 2000; Monsell, 2003). The third is updating, which refers to the ability to quickly monitor and evaluate incoming information relevant to the task at hand, and to use this information to revise what is currently active in working memory (Morris & Jones, 1990; Miyake et al., 2000). In a later revision of this model of EF, it was suggested that all these abilities load on a common (general) factor of executive functioning, but it has also been proposed that specific components of updating and shifting can be identified (Friedman & Miyake, 2017). This complexity in Miyake's model has been demonstrated through tests designed to measure different components of executive functioning, revealing that results from such tests have both unique and shared variance (Friedman & Miyake, 2017). Thus, this framework is sometimes referred to as the 'unity and diversity' view of EF.

In attempts to simplify the complexity of the conceptualization of EF, it has been suggested that so-called "game intelligence" (Stratton et al., 2004; Vestberg et al., 2012) is a related concept that is underpinned by an athlete's EF and is associated with level of athletic expertise (Hagyard et al., 2021). In support of this contention Vaughan and McConville (2021) highlight those athletes with higher level expertise in team sports (e.g., soccer, field hockey, rugby) outperform both lower division athletes and non-athletes on general (non-sport specific) measures of inhibition, shifting, and updating. Further research in soccer has identified that players who reach the national team, as opposed to players who "only" compete at the elite level, demonstrate better general EF (Vestberg et al., 2020). In the sport of ice hockey, Lundgren et al. (2016) tested players' general EF across various competitive levels; although, the players outperformed a standardized sample in aspects of planning ability, cognitive flexibility, and visual search, no differences were noted across players at different levels of competition. It warrants noting this study of hockey players did not examine the individual core components comprising the Miyake et al., (2000) model of EF (i.e., inhibition, shifting, updating), which could potentially result in different findings.

To advance both research and understanding of the applied performance implications of EF within specific sports, the components of EF warrant examination with consideration of both 'unity and diversity'. For example, to be successful in a game of ice hockey a player must have sufficient abilities to update (e.g., quickly identify and integrate new information into working memory during game situations), inhibit (e.g., ignore irrelevant stimuli that is not pertinent for optimal decision-making), and shift attention (e.g., quickly shift between different events on the ice). However, sport specific tests of these components of EF are not currently available for use in ice hockey.

In a meta-analysis undertaken by Kalén et al., (2021) the importance of distinguishing between domain-specific tests, which are developed to capture contexts of a particular sport, and tests that are more domain-general is highlighted. Across multiple studies sport-specific tasks are noted to be more effective than general tests in differentiating between elite and non-elite athletes (Mann et al., 2007; Travassos et al., 2013). Sport-specific tests, for instance, may include video clips of game situations in which responses involve physical actions such as passing a ball, making both the stimuli and the responses highly sport-specific. General tests on the other hand might include stimuli like arrows and responses given on a keyboard (e.g., flanker task; Eriksen & Eriksen, 1974). The issue of assessing cognitive performance in isolation from the actual sports context has been highlighted as a critical issue impeding sport science research, as it fails to capture the complexity of the demands inherent to the sport environment as well as athletes' sport specific performance strategies (Davis et al., 2022; Ericsson, 2003). However, general EF tests may still play a strategic role in sport research, and by considering recent findings highlighting the role of age in the association between executive functions and performance (e.g., Reinhard et al., 2025), they may still offer valuable insights when appropriately applied. First, they come with well-established psychometric properties, which allows findings to be compared across studies and populations (Friedman & Miyake, 2017). Second, they are practical, cost-efficient, and require less equipment. Third, even when they do not perfectly mirror game demands, they can reveal which core components of EF are plausibly linked to competitive success and may therefore be worth deeper investigation. Fourth, if a general test produces an intriguing pattern, it can serve as a starting point for designing sport-specific versions that capture the same component more sensitively within a realistic context, which has been deemed necessary in the literature (Davis et al., 2022)

Still, to bridge the gap between general testing and sport-specific demands, a promising approach is to manipulate stimuli within validated EF tasks. By replacing abstract symbols with game-specific cues, the test can retain its psychometric foundation while gaining ecological relevance. Empirical research shows that individuals process familiar stimuli more efficiently, drawing on prior knowledge structures that enhance both speed and accuracy (Krueger, 1975; Gauthier et al., 1999), and tests with manipulated stimuli may therefore be better suited to differentiate experts from non-experts. Thus, in the present study we also made specific modifications to the established general tests. In the sports versions of these tests, general stimuli (e.g., arrows) were replaced with hockey-specific stimuli (e.g., ice hockey players). These versions might be considered semi-variants of sports-specific tests, although it is important to note this modification supports the retention of their ability to measure executive functions reliably by using established test protocols (see e.g., Sörman et al., 2019). Specifically, this approach may determine whether the stimuli per se are important to consider and whether such manipulations can better differentiate athletes at different competitive levels in terms of accuracy and/or faster information processing compared to tests with general stimuli. Further, potential differences in test results between alternative versions of the same test may indicate that one version of the test is more sensitive than the other based on individual difference characteristics that are central to the population being studied (i.e., hockey players). This finding may lend important information regarding the usefulness of different test versions. In addition, it is important to clarify the relationships between test results from different EF tests (inhibition, shifting, and updating) as this forms a key aspect of evaluating the theoretical and practical implications of the results. The findings from sports modified versions may provide direction for the future development of lab-based tests with higher ecological validity.

This study contributes to the growing body of research seeking to balance methodological rigour with sport-specific relevance. While fully developed sport-specific tests are often difficult and resource-intensive to create, adopting existing EF tasks to capture cognitive demands in sport may offer a valuable and feasible first step in the design of more nuanced tests. The primary aim of this study was therefore to extend previous research that differentiates between ice hockey players across various levels of competition by using cognitive tests designed to assess EF. The secondary aims of this study were to investigate: (1) whether the type of stimuli used in EF tests (general stimuli vs. hockey-specific stimuli) influences the ability to differentiate players at varying levels of competition; (2) potential overall differences in results between different versions of the same tests; and (3) possible relationships between various outcome measures for the EF components (inhibition, shifting, updating).

Methods

Participants

Male ice hockey players (n = 39) playing in the Swedish senior league system were recruited through advertisements on platforms connected to Luleå University of Technology and via managers, coaches, and/or leaders in clubs who received information about the study. All subjects provided written informed consent in accordance with the Declaration of Helsinki, and the project was approved by the Swedish Ethical Review Board (Dnr 2021-02066). Participants were invited to participate at one test session, which focused on collecting information about their background in ice hockey and performing a computerized assessment of cognitive functions. The test session lasted approximately 1.5 hours. Participants were instructed to use corrected-to-normal vision if needed and to report any problems that might influence their performance (e.g., illnesses, problems with colour vision).

A major portion of the participants were right-handed (86.5%) compared to left-handed (8.1%). A minor portion of the sample stated that they were equally right and left-handed (5.4%). While a small portion of the testing was conducted in a laboratory at Luleå University of Technology, in most cases (n = 34), to reach ice hockey players representing different competition levels, mobility was necessary. Under such circumstances, only rooms that met test room requirements were used (e.g., privacy, closed, silence, good lighting, and comfort). The mean age of the sample was 23.49 years (SD = 3.76). Participants were skaters that had played ice hockey for an average of 18.08 years (SD = 3.94 years) and started playing at a mean age of 5.41 years (SD = 1.13).

Measures

Level of competition. Both current and highest achieved competitive level throughout the participation as an ice hockey player were used as indicators of level of competition. By including both of these measures it was possible to obtain an indication of whether cognitive functioning is associated with competitive level in the short term (a plausible dynamic relationship) and/or is related to the highest achieved level of competition, irrespective of the current level. This could be indicative of a more stable (static) relationship between executive functioning and expertise in ice hockey. For easier interpretation of results, higher competitive levels were assigned higher values. Players' current or highest achieved competitive levels ranged from the Swedish Hockey League (SHL, top-tier, professional; coded as 5), Hockeyallsvenskan (second-tier, professional; coded as 4), Hockeyettan (third-tier, semi-professional; coded as 3), Hockeytvåan (fourth-tier, amateur; coded as 2), down to Hockeytrean (fifth-tier, amateur; coded as 1). Participants' current competitive levels were distributed as follows: SHL, n = 3; Hockeyallsvenskan, n = 1; Hockeyettan, n = 13; Hockeytvåan, n = 20; and Hockeytrean, n = 2. Regarding highest achieved competitive level, the distribution was: SHL, n = 5; Hockeyallsvenskan, n = 1; Hockeyettan, n = 20; Hockeytvåan, n = 12; and Hockeytrean, n = 1.

Cognitive assessment. All cognitive tasks included in the test-battery were programmed in E-Prime 3.0 (Schneider et al., 2002). Performance on all tasks was based on the cognitive processing of visual non-verbal stimuli; participants were instructed to respond as quickly and accurately as possible. Cognitive testing was conducted on a 15-inch Dell Latitude 7530 laptop equipped with a 12th generation Intel® Core™ processor. The distance between the face of the participant and the screen was approximately 50-60 cm.

Inhibition. Two versions of the stop-signal task (Logan & Cowan, 1984) were used as a measure of response inhibition. In the more general version of the test (available in the E-prime 3.0 Experiment Library, and further programmed into a Swedish version of the test) participants were instructed to determine as quickly as possible the direction of a black arrow surrounded by a black circle presented one at a time, at the centre of a screen with a white background. A fixation cross (+), also surrounded by a circle, was displayed for 250 ms, followed by the stimulus which was displayed for 500 ms. In some trials, the black circle that surrounded the arrow was red (stop-signal). Under such circumstances, participants should inhibit their automatic response and not respond using the keyboard. Instead, they should wait until the next arrow appeared on the screen. The task began with 10 practice trials, followed by 150 test trials, which included stop-signal trials.

In the version of the stop-signal task using hockey stimuli, participants were required to determine the direction in which an ice hockey player on the ice was pointing, either to the left or right. In some trials, an opponent stood close behind the player (stop-signal). In these trials, participants were instructed to inhibit the automatic response and not to respond to the direction of the player. The version of the stop-signal task using hockey stimuli followed the exact same procedure as the general version of the task, with the only modification being the stimulus used. Two measures were used as performance indicators of response inhibition: (1) Total Accuracy, and (2) a standardized composite score taking both total accuracy and reaction times in go trials into account. An illustration and more detailed description of the two versions of the stop-signal task can be seen in Supplementary Material S1 file.

Shifting. Two versions of the Color-Shape task were used to measure shifting ability. The general version was based on the one used by Prior and Macwhinney (2010). For majority of the test, participants were required to shift between determining either the colour or the shape of a figure presented at the centre of the screen (3x48 trials), meaning that they would either shift in their categorization (e.g., from colour to shape or vice versa) or continue categorizing similarly to the previous trial (e.g., colour). Each trial began with a fixation cross presented at the centre of the screen for 350 ms, followed by a blank screen displayed for 150 ms. The figure was presented on a white screen and could be either a blue circle, a blue triangle, a red circle, or a red triangle. Whether participants should focus on the colour or the shape of the figure was determined by a pre-cue displayed on the screen. This pre-cue, shown for 250 ms before the figure appeared, was either a rainbow, indicating that they should focus on the colour of the figure, or a black circle embedded within a black triangle, indicating that they should focus on the shape of the figure. The pre-cue remained on the screen, just above the figure, until a response was given.

In the version with hockey stimuli, participants were required to determine either the colour or the shape (i.e., position) of an ice hockey player presented on the screen. If the pre-cue was a rainbow, participants should, similar to the general version, focus on the colour of the player (red or blue jersey). If the pre-cue consisted of arrows indicating two different directions, the task was to identify the player's position (offensive or defensive). Apart from the differences in the stimulus and one of the pre-cues, the procedure was identical to the general version of the task.

Three performance measures were used as indicators of shifting ability: (1) total accuracy, (2) the difference in accuracy between shifting and non-shifting trials (referred to as accuracy shift costs), and (3) the difference in average RTs between shifting and non-shifting trials (referred to as reaction time shift costs). An illustration and more detailed description of the two versions of the Color-Shape task can be seen in Supplementary Material S1 File.

Updating. Two versions of the visual 2-back task were used to measure updating ability. In the general version (Kirchner, 1958, see also Forsyth et al., 2021), a black arrow was presented on a white screen one at a time. The arrow pointed in one of five directions (left, left diagonally, straight ahead, right diagonally, right). The task was to determine whether the arrow displayed was identical (i.e., pointing in the same direction) as the arrow shown two steps earlier by responding using the keyboard. (e.g., ← = no, ↘ = no, ← = yes, → = no, ↘ = no, → = yes). Each arrow was displayed for 2500 ms at the center of the screen, followed by a 2000 ms blank interval. The task started with 15 practice trials, followed by 40 test trials.

In the version of the 2-back task in which hockey stimuli were used, the stimuli consisted of an ice hockey player in an all-black uniform who could move in five directions (left, left diagonally, straight ahead, right diagonally, right). Apart from these differences in stimuli, the version with hockey stimuli task followed the same procedure as the general version. The total accuracy in the tasks was used as a measure of updating ability. An illustration and more detailed description of the 2-back task can be seen in Supplementary Material S1 File.

Statistical analysis

In all analyses aimed at investigating whether it is possible to differentiate players at different levels of competition regarding EF, within-group analyses were conducted, treating indicators of cognitive performance as continuous variables. Outliers were excluded from all test results using the Interquartile Range Rule (Tukey, 1977).

First, descriptive statistics were calculated, and skewness and kurtosis were used to evaluate deviation from normality. Second, bivariate correlations were conducted to investigate relationships between variables included in this study, with particular interest in the associations between indicators of the level of competition and cognitive outcomes. Third, to further explore the relationships between the level of competition and cognitive functioning, two-step hierarchical multiple regression analyses were performed. Cognitive performance in each test (general and hockey-specific) was treated as a dependent variable in separate models. In Step 1 (i.e., Model 1), covariates age and years of education were entered as independent variables. In Step 2 (i.e., Model 2), level of competition was included as an independent variable. The rationale for using this two-step approach was to calculate the R square Change (ΔR^2), representing the unique explained variance, essentially a measure of effect size, of level of competition on each cognitive measure once the influence of the covariates had been controlled for. In addition, associations between level of competition and cognitive performance were investigated using 95% confidence intervals and p-values. The significance level (α) was established to 0.05 and all analyses were executed using SPSS version 28.

Finally, paired sample t-tests were conducted to compare test scores of participants in the general and hockey-specific stimulus conditions for each test. Results from bivariate correlations were used to investigate relationships between EF test results.

Results

Descriptive statistics for all study variables including mean values, standard deviations, min-max values, skewness and kurtosis, and with cognitive outcomes categorized under the headings of their respective subdomains of executive function (inhibition, shifting, updating) are presented in Table 1.

Table 1: Means, standard deviations, min/max values, skewness and kurtosis for all variables used in the present study

	M	*SD*	Minimum	Maximum	Skewness^c	Kurtosis^d
Age	23.49	3.76	18	30	0.08	-0.91
Years of Education	12.59	1.44	11	17	2.12	3.89
Level of competition - highest^a	2.93	0.98	1	5	0.86	0.59
Level of competition - current^a	2.56	0.94	1	5	1.21	1.65
Inhibition						
Stop signal - Total accuracy	143.15	5.32	128	150	-1.21	1.73
Stop Signal - Total Accuracy/Reaction time^b	0.00	1.00	-1.68	2.25	-0.87	0.38
(H) Stop signal - Total accuracy	133.41	10.92	105	145	-0.97	-0.02
(H) Stop Signal - Total Accuracy/Reaction time^b	0.00	1.00	-2.42	1.32	-0.86	-0.24
Shifting						
Color Shape - Accuracy	133.62	5.41	118	141	-0.95	0.59
Color Shape - Shift cost (ACC)	3.33	4.50	-4	13	0.66	0.01
Color Shape - Shift cost (RT)	126.33	91.35	5	332	0.76	-0.59
(H) Color Shape - Accuracy	135.26	4.38	124	143	-0.70	0.15
(H) Color Shape - Shift cost (ACC)	2.69	2.81	-4	9	0.38	0.27
(H) Color Shape - Shift cost (RT)	82.84	52.09	-21	204	0.37	0.31
Updating						
Visual 2-back - Accuracy	34.43	5.19	22	40	-0.86	-0.07
(H) Visual 2-back - Accuracy	33.53	5.32	22	40	-0.46	-1.07

H = Hockey stimuli; ^{a}1 = Third division, 5 = Highest division (SHL); ^{b}Standardized composite score taking both total accuracy and reaction times in go trials into account; ^{c}Std Error = .378 - .398; ^{d}Std Error = .741 - .778

As can be seen from analyses of normality, the skewness for all variables ranged from -1.28 to 2.12, and kurtosis ranged from -1.07 to 3.89. Some literature suggests a threshold around ±2 for skewness and ±7 for kurtosis (e.g., Finney and DiStefano, 2006; Hair et al., 2010). Consequently, this study's data overall could be considered as normally distributed. Next, bivariate correlations were executed between study variables. The results from these analyses are presented in Table 2.

Table 2: Correlations between variables included in the present study

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Age																
2. Years of Education	.414*															
3. Level of competition - highest	-.075	-.170														
4. Level of competition - current	-.169	-.110	.816**													
5. Stop signal - Total accuracy	.250	.285	.329*	.360*												
6. Stop Signal - Total Accuracy/Reaction time	.406*	.183	.409*	.306*	.788**											
7. (H) Stop signal - Total accuracy	.482**	.116	.282	.190	.519**	.755**										
8. (H) Stop Signal - Total Accuracy/Reaction time	.463**	.158	.313	.159	.491**	.783**	.904**									
9. Color Shape - Accuracy	.227	.219	.121	.088	.633**	.542**	.345*	.386**								
10. Color Shape - Shift cost (ACC)	-.312	-.171	.178	.066	-.240	-.067	-.067	.033	-.535**							
11. Color Shape - Shift cost (RT)	-.052	-.056	-.076	-.016	-.213	-.282	-.421**	-.379*	-.305	.142						
12. (H) Color Shape - Accuracy	.282	.127	-.103	-.116	.349*	.310	.315	.292	.627**	-.447**	-.302					
13. (H) Color Shape - Shift cost (ACC)	-.048	-.029	-.018	.047	-.116	-.145	-.166	-.197	-.256	.164	.292	-.353*				
14. (H) Color Shape - Shift cost (RT)	-.183	-.069	-.087	-.065	-.112	-.191	-.361*	-.333*	-.341*	.149	.521**	-.313	.440**			
15. Visual 2-back - Accuracy	.146	-.127	.241	.217	.299	.367*	.473**	.398*	.246	-.005	-.291	.269	-.145	-.291		
16. (H) Visual 2-back - Accuracy	.125	.184	.332*	.301	.323	.398*	.408*	.340*	.291	.036	-.409*	.321	-.230	-.282	.679**	

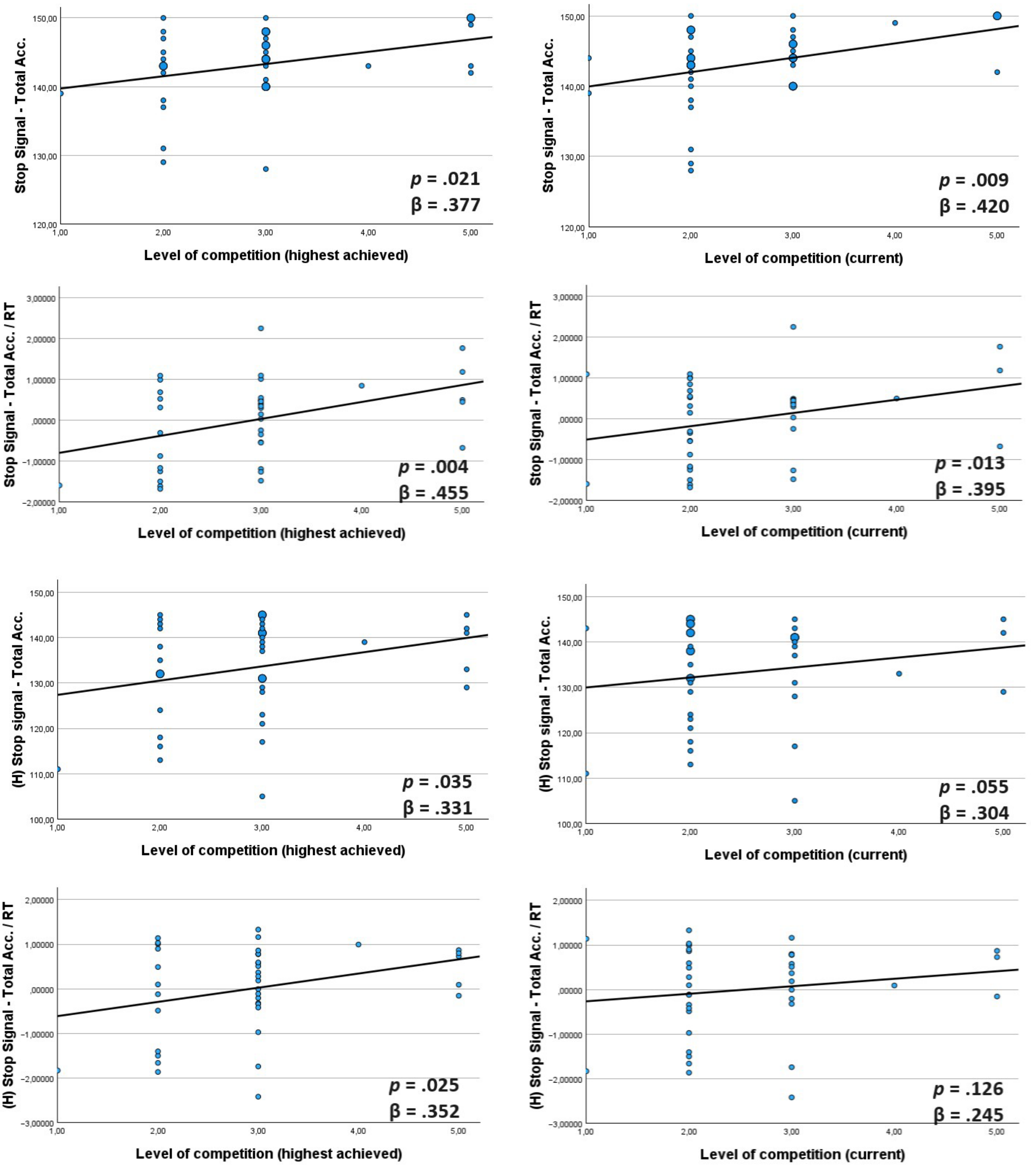
H = Hockey stimuli; *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Results from correlational analyses revealed that highest achieved competitive level was positively and moderately correlated with total accuracy in the general version of the stop-signal task (*r* = .329, *p* = .041) and with the standardized composite score of the test taking both total accuracy and reaction time into account (*r* = .409, *p* = .010). Highest achieved competitive level was also significantly correlated with accuracy in the version of the visual 2-back task in which hockey stimuli was used (*r* = .332, *p* = .048). Current competitive level was also significantly correlated with total accuracy in the general version of the stop-signal task (*r* = .360, *p* = .024).

Among the covariates, higher age, which in this context also can be indicative of being more experienced as ice hockey player, was associated with better performance regarding both standardized composite scores (accuracy/reaction time) of the stop-signal task (general stimuli, *r* = 406, *p* = .010; hockey stimuli, *r* = .463, *p* = .003). Age was also associated with better performance in the Stop-signal test in which hockey stimuli was used (total accuracy, *r* = .482, *p* =.002).

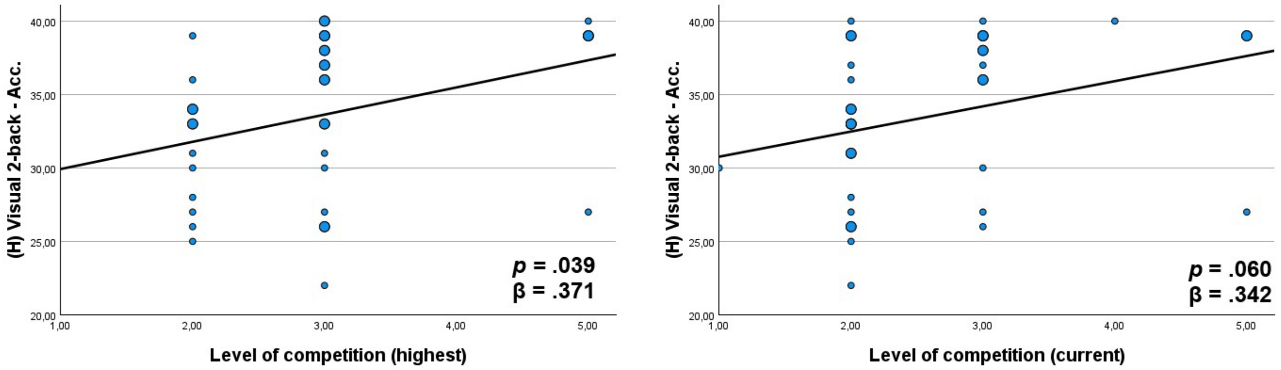
Next, hierarchical multiple regression analyses were conducted. Graphs illustrating significant and borderline significant regression lines between the level of competition and cognitive outcomes found in this study are displayed in Figure 1 and 2.

Figure 1. Graphs show significant (and borderline significant) regression lines between level of competition and indicators of performance in the Stop-signal task, used as measure of response inhibition. Graphs including highest achieved level of competition as independent variable are displayed on the left side. Graphs including current level of competition as independent variable are displayed on the right side.



Note.
H = Hockey stimuli
1 = Third division; 5 = Highest division (SHL)
Larger dots indicate that more than one participant had the same value.
First row = Total accuracy in the Stop signal task (general version)
Second row = Score considering both accuracy and reaction time (general version)
Third row = Total accuracy in the Stop signal task (hockey stimuli)
Fourth row = Score considering both accuracy and reaction time (hockey stimuli)

Figure 2. Graphs show significant (and borderline significant) regression lines between level of competition and performance in the Visual 2-back task (hockey stimuli), used as measure of updating ability. Graph including highest achieved level of competition as independent variable is displayed on the left side. Graph with current level of competition as independent variable is displayed on the right side.



Note.
H = Hockey stimuli
1 = Third division; 5 = Highest division (SHL)
Larger dots indicate that more than one participant had the same value.

Results from hierarchical regressions, with age and years of education as covariates in step 1, and level of competition in step 2 (separate models for each indicator) were similar to those obtained from the correlational analyses.

For response inhibition, it was found that highest achieved level of competition was positively associated with total accuracy (β = .377, 95% CI [0.33, 3.73], *p* = .021), and with the composite score, indicative of both accuracy and reaction time (β = .455, 95% CI [0.15, 0.72], *p* = .004) in the general version of the stop-signal test. It explained 13.8% of the variance using total accuracy as the indicator of performance, and 20.1% in the composite score. Highest achieved level of competition was also related to higher accuracy (β = .331, 95% CI [0.24, 6.24], *p* = .035) in the version of the test where hockey stimuli were used, showing a significant increment in the explained variance (ΔR^2 = .106), and with the composite score when hockey stimuli were used (β = .352, *p* = .025; ΔR^2 = .121).

A similar pattern for performance in the Stop-signal task emerged for the current level of competition, which was associated with higher total accuracy (β = .420, 95% CI [0.63, 4.09], *p* = .009), and higher values in the composite score (β = .395, 95% CI [0.09, 0.70], *p* = .013). It explained a reasonable amount of variance regarding both total accuracy (*ΔR2* = .171) and the composite score (*ΔR2* = .151). Regarding total accuracy in the version of the stop-signal test in which hockey stimuli were used, current level of competition was borderline significant with performance (β = .304, 95% CI [-0.07, 6.23], *p* = .055, *ΔR2* = .090).

Regarding updating ability, analyses showed that the highest achieved level of competition was significantly related to better performance in the visual 2-back test where hockey-specific stimuli were used (β = .371, 95% CI [0.11, 3.95], *p* = .039), showing an increase in the explained variance for performance in the test (*ΔR2* = .130). An association with performance in this test was almost significant for the current level of competition (β = .342, 95% CI [-0.08, 3.88], *p* = .060, ΔR^2 = .109). None of the indicators of level of competition were related to performance in the general version of the test (highest level, *p* = .213; current level, *p* = .179). Indicators of level competition were not significantly associated with any measure of shifting ability.

Finally, covariates had a minor influence on performance in cognitive tests. Higher age, which may be indicative of more experience as an ice hockey player, was related to better response inhibition as shown by increased total accuracy in the stop-signal test (β = .426, 95% CI [0.20, 2.07], *p* = .019) in the version of the test using hockey stimuli. Results showed that years of education was not significantly related to performance in any cognitive test. Results from all hierarchical regression models can be found in Supplementary material S2 File.

Results from paired sample t-tests, undertaken to investigate potential overall differences in test results between different versions of the same tests (general vs. hockey stimuli), revealed some significant differences. There was a significant difference in total accuracy between the general (*M* = 143.15, *SD* = 5.32) and hockey specific stimuli (*M* = 133.41, *SD* = 10.92) conditions of the stop-signal test, *t*(38) = 6.51, *p* < .004, *d* = 1.04). This indicates a large effect size, suggesting that the difference in accuracy between the two conditions is substantial. The hockey players in this study had higher accuracy scores in the general version of the test, indicating that they found the hockey version of the test more challenging at the group level. It should be noted that for the test using hockey stimuli the standard deviation was larger, indicating more variability in the data.

For the color-shape task, participants had significantly higher accuracy ($t(34) = -2.72$, $p = .010$, $d = -0.46$) when hockey stimuli were used ($M = 135.60$, $SD = 4.22$) compared to general stimuli ($M = 133.63$, $SD = 5.41$). This indicates a small to medium effect size, suggesting that the use of hockey stimuli led to a modest improvement in accuracy. Participants also showed a lower RT shift cost in the hockey version of the test ($M = 82.84$, $SD = 52.08$) than in the general version ($M = 120.92$, $SD = 86.01$), $t(37) = 3.18$, $p = .003$, $d = 0.52$. This indicates a medium effect size, suggesting that the hockey version of the test resulted in a moderate reduction in reaction time shift costs. Beyond this, no significant differences were found between the different outcome measures for different test versions.

Regarding the relationships between the different outcome measures for the various EF components included in this study (evaluated through bivariate correlations), it warrants noting that, as expected, the results revealed many significant correlations between outcome measures used as performance indicators within each cognitive test. Examining each core component of EF further, starting with the stop-signal task as a measure of response inhibition, total accuracy scores from the two versions of the test correlated significantly ($r = .519$, $p < .001$). Similarly, the composite score, indicative of both accuracy and reaction time, showed a strong correlation between the versions of the test ($r = .783$, $p < .001$). Regarding shifting ability, accuracy scores from the two versions of the color-shape test were significantly correlated ($r = .627$, $p < .001$), as was shift cost in reaction time ($r = .521$, $p < .001$); although a significant relationship was not observed for accuracy shift cost ($r = .164$, $p = .318$). Finally, for the visual 2-back task, indicative of updating ability, accuracy scores for each version of the test were strongly correlated ($r = .679$, $p < .001$).

Results from the correlation analyses also revealed some interesting and significant correlations between outcome measures across EF components. The accuracy score in the general version of the color-shape task strongly correlated with the total accuracy score from the general stop-signal test ($r = .633$, $p < .001$). It was also significantly correlated with the composite score ($r = .542$, $p = .001$), as well as with outcome measures from the stop-signal test using hockey stimuli (total accuracy, $r = .345$, $p = .042$; composite score, $r = .386$, $p = .001$), although these relationships were weaker. The accuracy score in the hockey version of the color-shape task was also significantly correlated with total accuracy score in the general version of the stop-signal test ($r = .349$, $p = .032$). Additionally, lower shift cost (RT) in both the general and hockey-specific versions of the color-shape task correlated significantly with all outcome measures used as performance indicators for the hockey version of the stop-signal test, with r-values ranging from -0.333 to -0.421.

Both versions of the visual 2-back task had a strong correlation ($r = .679$, $p < .001$). In addition, the general version of the 2-back task was significantly and moderately correlated with performance measures from both versions of the stop-signal test (composite score in the general version, $r = 0.367$, $p = .026$; total accuracy in the hockey version, $r = 0.473$, $p = .003$; composite score in the hockey version, $r = 0.398$, $p = .015$). Similarly, the hockey version of the 2-back test was significantly correlated with outcome measures from the stop-signal tests (composite score in the general version, $r = 0.398$, $p = .015$; total accuracy in the hockey version, $r = 0.408$, $p = .014$; composite score in the hockey version, $r = 0.340$, $p = .043$).

In summary, the significant correlations both within and across core components of EF, as well as the examples of non-significant associations within components, highlight the complexity of EF in terms of both its unity and diversity.

Discussion

The primary aim of this study was to investigate whether results from tests of EF can differentiate ice hockey players across various levels of competition. A secondary aim was to explore whether the type of stimuli used in the EF tests (general vs. hockey-specific) were able to delineate players across competitive levels. The study also examined variations in test results for different versions of the same tests, regardless of the level of competition. Differences in results could indicate that one version is more sensitive to the population being studied, providing valuable insights for developing lab-based tests. Finally, the study explored relationships between performance measures of EF components (inhibition, shifting, updating), which is crucial for evaluating the theoretical and practical implications of the results.

Findings revealed that higher competitive level was associated with better performance in tasks measuring inhibition and updating but not shifting. Notably, superior updating performance was only observed in the hockey-specific version of the 2-back test. Overall performance differences between test versions were also found, including lower accuracy in the hockey-specific stop-signal task and slightly higher accuracy in the hockey-adapted color-shape task, suggesting that stimulus complexity and task characteristics interact. Correlational analyses further supported the unity and diversity of EF, with inhibition measures showing the strongest and most consistent relationships, both within and across components.

EF and level of competition

Taking into consideration results from the hierarchical multiple regression analyses, the data showed significant linear trends reflecting that the higher competitive level the better the ice hockey players' updating ability and inhibitory control. These findings were evident across several outcome measures included in the study. Superior EF has been shown to relate with successful sports performance in previous research (see e.g. Scharfen & Memmert, 2019; Vaughan & McConville, 2021; Vestberg et al., 2012; 2020). While based on a limited sample, the present findings suggest that specific components of EF (updating and inhibition) could also be linked to level of expertise in ice hockey, even when controlling for age, which has been identified as a key factor in the association between executive functions and performance (Reinhard et al., 2025). This indicates that the observed differences in EF cannot be solely attributed to greater cognitive maturity or experience among older players. Rather, the relationship between higher EF and competitive level appears to reflect domain-specific cognitive advantages that go beyond general age-related cognitive development.

Regarding response inhibition, the findings from the stop-signal tests suggest that the ability to restrain automatic but inefficient responses is more developed in higher level players; as such, inhibitory control observed in a lab-based setting may transfer to successful performance in competition. This finding, which aligns with previous studies investigating the role of inhibitory control within a broader team sport category (Fledderman et al., 2023), can guide future sports research targeting the training of cognitive abilities that underpin success in ice hockey specifically. However, these results should still be interpreted with caution as attempts to replicate these findings are warranted prior to the development of interventions and generalisation of potential applied implications. Additionally, we cannot rule out the possibility that better inhibitory control might also reflect general individual difference factors such as self-regulation (Durand-Bush et al., 2023) or grit (Cormier et al., 2024) that may foster behaviours that are beneficial for elite level performance. Nonetheless, the finding that inhibition related to level of competition in ice hockey players supports the proposal of Friedman and Miyake (2017) in a revised model of EF that suggests tests of inhibition load on a common EF factor. As such, it could be argued that general EF is an important factor for success in ice hockey.

The observed finding that superior updating ability is related to a higher level of competition may indicate that the ability to rapidly monitor and evaluate incoming information is an important factor to perform at the top level in ice hockey. Updating ability has been related to athletic expertise in team sports in previous studies (Vaughan & McConville, 2021), however this is the first study to observe this pattern in ice hockey. More specifically, better accuracy on the 2-back test using hockey-specific stimuli may indicate superior working memory capacity for players competing at higher levels (Morris & Jones, 1990; Miyake et al., 2000) and could offer a focus for future research.

Shifting ability, however, was not found to significantly relate to participants' level of competition. This initially appears to be an unexpected result as the ability to shift quickly and accurately between different tasks and/or mental states during a game is intuitively an important factor for sport performance. However, it is possible that on-ice decision-making and 'game intelligence' may be better represented by other EF components than shifting ability. We are unable to determine if the test used in this study, (i.e., Color-Shape task) was suitable for capturing the type of shifting ability required in ice hockey. The extant literature comprised of studies beyond the domain of sport, outlines a variety of tests for assessing shifting capacity with mixed results indicating alternative tests capture different aspects of cognitive control (Hsieh, 2012). The choice of this test (Color-Shape) in the present study was based on its use in other occupational contexts (e.g., Sörman et al, 2019), but this does not exclude the possibility that other tests of shifting ability might have better predictive power in the sports context. This methodological issue highlights the need for cognitive tests designed for the domain sport and potentially sport-specific tests to reflect varying performance factors (i.e., game speed, number of competitors).

The results from this study overall display very similar patterns regardless of whether current or highest level of competition was used as the dependent variable in the analyses. The rationale for including both measures was to investigate if EF has a more dynamic (reciprocal) relationship with level of competition, which plausibly would be evident if current level had a stronger relationship with EF than the highest level. However, the results indicate that these outcome measures were highly correlated, reflecting that most of the players included in this study currently compete at the highest level they have ever achieved. Therefore, the sample in present study precludes the investigation of whether EF has a more dynamic or static relationship with these measures. Future longitudinal studies could elucidate the relationship between EF and level of competition over time, with the aim of advancing approaches to targeting key stages of development for the use of cognitive training to improve performance.

Among the covariates in this study, it was found that increasing age was associated with better inhibitory control across several outcome measures from the stop-signal test. Although the narrow age range (i.e., 18-30 years) in the present study warrants noting, the better inhibitory control displayed by the more experienced players (i.e. older) may have implications for on ice performance and requires further study.

The influence of stimuli on the ability to differentiate players at varying levels of competition

Overall, the results from this study suggest that the relationship between the level of competition and inhibitory control was relatively similar regardless of whether general or sport-specific stimuli were used. This finding was observed on outcome measures of the stop-signal test reflecting total accuracy and the standardized composite score (i.e., total accuracy and reaction time). Specifically, statistical differences were minor with slight changes in p-values and/or small beta weights depending on the analyses. This may indicate a general test of inhibition - at least the one used in this study - can be just as useful as a semi-variant using hockey stimuli in differentiating hockey players across competitive levels. However, from an information processing perspective, it is possible that the hockey-specific stimuli used in this study increased task difficulty compared to the general test. This might be reflected in the fact that the overall sample showed higher accuracy (mean value) in the general test than in the version comprised of hockey stimuli. Despite this, no differences were found between the two versions in their ability to differentiate players across levels of competition.

However, between the two versions of the test measuring updating ability, a different pattern emerged. The relationship between performance on the visual 2-back test and level of competition was only significant when hockey-specific stimuli (hockey players) were used. This effect was observed in relation to the highest achieved level of competition; the relationship between current level and updating ability on the hockey specific test was borderline significant. Nevertheless, no significant relationships were found between any measure of competitive level and updating ability in the version of the test using general stimuli (arrows). This finding highlights the nature of the test stimuli may be an important factor to consider in future research.

Attempts to explain why the effects of different stimuli were observed in the updating test but not in the inhibition test are somewhat speculative yet can be related to previous research, the test characteristics, and aspects of EF. Specifically, performance on the inhibition test (stop-signal) requires participants to make decisions as quickly and accurately as possible with stimuli presented for a maximum of 500 ms. As such, stimuli exposure and subsequent decision-making must happen immediately which may impede any effects associated with variation in stimuli characteristics (although this may seem counterintuitive from an information processing perspective). In contrast, the updating test presents stimuli for a longer period (2500 ms) and requires participants to encode the stimuli to be able to determine if it is the same stimulus that is presented two steps later. It is possible that in this process, which involves "more" encoding of hockey-specific material and to keep it active in working memory, is more developed among experts. However, it should be noted that overall, and as will be discussed later, the two versions of the 2-back test appeared to have similar difficulty level as the sample's overall performance (mean scores) on the tests were similar. Still, the finding that the version using hockey-related stimuli better differentiated players at different competitive levels may reflect the benefits of increasing ecological relevance, in line with research showing that sport-specific tasks are generally more effective than general tests in distinguishing between elite and non-elite athletes (Mann et al., 2007; Travassos et al., 2013). However, we acknowledge that our tests involved only a manipulation of stimuli rather than fully sport-specific test. In this study, we can add to previous research by showing that a manipulation of an updating test provides more detailed insights into players' updating ability. Therefore, this result may provide a valuable direction for future research in developing lab-based updating tests with higher ecological validity.

Overall differences in test results between alternative versions of the same test

Results showed differences in task performance in the stop-signal test, indicative of inhibition, with participants overall having higher accuracy scores in the general version of the test. Thus, participants (i.e., ice hockey players) did not as a whole benefit from using familiar hockey-related stimuli. On the other hand, stimuli like arrows are simple and not unfamiliar to participants either. The hockey stimuli used in this test were relatively complex compared to arrows, involving a player (and sometimes even an opponent) in a hockey environment, providing more information to process, and on which participants should make their decisions (give response/inhibit response). This higher level of difficulty may also be reflected in the higher variability observed between participants for this version of the test. This finding may suggest that the ice hockey version of the test could be more useful in future research due to its greater ecological validity. By more closely resembling the actual and potentially more complex demands faced by players during a game, it may provide more accurate insights into their inhibitory control in real-world scenarios. Still, both versions were able to differentiate players at different levels of competition. It would be interesting for future research to also explore whether hockey players differ from the general population (or other specific populations) in their performance on the two versions of the test, which would provide valuable insights into their validity in different populations.

Significant differences in overall test results were also observed for the color-shape task (shifting), with higher accuracy scores when hockey stimuli were used. This finding is in contrast with the results from the stop-signal test, although the performance differences between versions were not as pronounced as in the stop-signal test. This highlights the complexity involved in manipulating stimuli and the need to consider various aspects. In this case, the answer for the difference found likely lies in both the complexity of the stimuli and the nature of the task. In this task, identifying features such as the colour or shape of hockey players (likely less complex), participants' familiarity with hockey players, and increased engagement with relevant stimuli might have contributed to the higher accuracy scores, although this is highly speculative. Nonetheless, neither version of the color-shape task was able to differentiate players at different competitive levels. Nonetheless, neither version of the color-shape task was able to differentiate players at different competitive levels. Further research is needed to refine methods using hockey-specific stimuli in this or similar shifting tasks, potentially by incorporating more dynamic or interactive elements to better capture the cognitive demands of shifting in hockey.

Relationships between outcome measures and components of EF

The significant correlations observed both within and across EF components were somewhat expected, as EF is a higher-order construct composed of three subcomponents. Moreover, the findings revealed that the same performance indicators used for the two versions of the same test (general vs. hockey-specific) showed, on the whole, moderate to strong correlations. These results underscore the coherence of EF as a construct and its measurable components.

However, some interesting exceptions to this pattern were observed. Within components, results from the color-shape task, indicative of shifting ability, showed no correlation between accuracy shift cost of the two versions of the test. This discrepancy may suggest validity concerns, although it is difficult to interpret the cause of this discrepancy. As noted previously, no outcome measures used for these tests were related to the level of competition. That said, the general version of the test has been shown to be a valid instrument and has been used in other studies beyond the domain of sport (e.g., Paap & Greenberg, 2013; Sörman et al., 2019). Further studies should investigate whether alternative measures of shifting would reveal different outcomes than those found in this study. Nevertheless, although some exceptions were observed, the overall results still demonstrated significant correlations within components.

Across components, if was found that several outcome measures from both versions of the stop-signal test (inhibition) demonstrated significant correlations with performance measures in the color-shape task (shifting). Several significant correlations were also found for outcome measures from the stop-signal tests with performance in the 2-back tests (updating). As noted, significant correlations across different components can be expected, considering the unity and diversity of EF (Miyake et al., 2000). Still, the overall finding from this study that shifting and inhibition, as well as updating and inhibition, and to a lesser extent shifting and updating, share mechanisms is in line with what has also been proposed in the literature: that updating and shifting can be identified as separate factors under a common general factor, and that inhibition is more representative of this general factor (Miyake & Friedman, 2012). This finding is intriguing not only from a psychometric perspective, but also for applied research. In this study, we found that several outcome measures used as performance indicators of inhibition were related to level of competition. That fact that inhibition in turn can be related to performance in the other two EF components, may indicate that inhibition is the core component offering the greatest potential return on the investment of effort in cognitive training. As such, applied research and performance may be well served by testing interventions targeting inhibition. This is particularly relevant in elite sports contexts, where training time is limited and cognitive training needs to be both time-efficient and effective. If inhibition can positively impact other EF domains as well as performance, targeted interventions may offer a strategic and resource-efficient way to support the development of cognitive aspects of elite ice hockey performance.

Strength and Limitations

Although there are several strengths to this study, there are also a number of limitations that must be acknowledged. While the aim was to investigate how EF differs depending on level of competition, the recruitment of more players from both the upper and lower levels comprising the league system may have increased the likelihood of identifying differences between novices and experts. Additionally, the direction of causality between the factors cannot be established based on the research design of the study and the cross-sectional analysis of competition levels.

The study's findings have the potential to support cognitive training efforts with ice hockey players; however, it is important to emphasize that the findings are preliminary and need to be replicated in future research. That said, the results indicate EF, specifically inhibition and updating, can be related to level of competition; as such, cognitive training targeting these functions could be integrated into individualised training programs wherein an athlete's cognitive profile indicates that a specific function requires improvement. In such cases, cognitive training could be carried out alongside other training activities (e.g., physical, technical, tactical) with the aim of optimising decision-making and game intelligence to benefit on-ice performance.

Furthermore, in elucidating individualized cognitive profiles, it is possible that cognitive screening has a potential play a role for talent identification. However, caution is warranted with this approach, as it is plausible that EF develops at different rates. It should also be noted that cognition represents only one piece of the puzzle in ice hockey. Moreover, this study cannot provide evidence of causality; it is possible that EF improves due to other aspects of development as a hockey player (e.g., cumulative exposure to match situations), rather than being a predictor of future success in the sport.

Conclusions and future directions

Results from this study revealed significant associations between a higher competitive level in ice hockey and measures of inhibitory control and updating ability. While preliminary, these findings highlight the potential relevance of EF in ice hockey performance; an increased understanding of EF in hockey can guide applied aspects of performance as well as future research. Future studies should further validate the findings from this study, include more players from both the upper and lower levels of the league system, but also compare the performance of ice hockey players with that of the general population. Longitudinal studies are also warranted to investigate how EF and level of competition interact over time as well as elucidate the causal relationship between these factors. Additionally, research should explore the characteristics of the stimuli used in different test versions to support the creation of lab-based tests with stronger ecological validity. Building on these results, sport-specific EF assessments could be designed to better reflect domain-relevant challenges and improve sensitivity in distinguishing between levels of expertise. Ultimately, if confirmed and extended, these findings may also guide cognitive training strategies aimed at enhancing performance in ice hockey.

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