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Original Research

Relationships of executive functions and game intelligence in adolescent ice hockey players

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Background and Aim

In ice hockey, players are forced to process information from their environment to make optimal decisions and initiate appropriate actions as quickly as possible. This process involves executive functions and contributes to game intelligence, which describes the adequate solving of sport-specific problems. This relationship has only been sparsely investigated in ice hockey, which serves as a rationale for this study´s aim to make further statements about the relationship between executive functions and game intelligence.

Methods

Players of a German junior ice hockey team (n=10) aged, 17.3±1.0 years were randomly selected for the study to participate in the Trail Making and Design Fluency Test. Hockey-specific game intelligence was determined by the Game Performance Assessment Instrument. Data were analysed using correlation and linear regression.

Results

Results revealed significantly strong correlations (r=0.683, p=0.04) between executive functions measured by Trail Making Test and game intelligence. No significant correlations were found for the executive functions measured by Design Fluency Test. Furthermore, no correlation was found between age or playing experience and game intelligence.

Conclusions

Results indicate a strong correlation between executive functions expressed by trail making and game intelligence. Design fluency did not show any correlation to game intelligence.

Practical Implications

To address game intelligence as a performance-determining factor, the executive functions expressed by Trail Making should be included in training and talent assessment. Further research with larger samples including players from different positions, different playing and age groups are necessary to explain the presented relationships more accurate.

INTRODUCTION

Although performance assessment in sports is strongly linked to the assessment of physical performance, the cognitive abilities of athletes can significantly determine the level of performance.[1,2] Based on the physical and cognitive demands of the respective sport, a distinction is made between open and closed skill sports. Closed skill sports are self-paced, and athletes follow predetermined movement patterns. These sports take place in a more predictable and stable environment. In contrast open skill sports are externally paced. Athletes must adapt to dynamic situations and environments and react accordingly.[3] Open skills sports can again be classified according to their general character, interceptive sports and strategic sports. Interceptive sports require a high level of coordination of the entire body or parts of the body, or the equipment used. Strategic sports are defined as sports in which participants must simultaneously process a range of complex information about the trajectory of game objects, the position of team members or opponents, defensive and offensive tactics and general strategy.[4] Therefore, cognitive functions and the extent to which these are present can play a crucial role in certain situations.[5,6]

Cognitive functions are best defined as mental processes which are involved in the acquisition, processing and storage of information. This includes both conscious and unconscious processes of stimulus processing of information external to the organism or information internal to the organism.[7] Cognitive functions are divided into basic and higher cognitive functions. Basic cognitive functions such as attention, awareness and concentration are significant factors that can have an impact on the performance of an athlete.[1] Higher cognitive functions include perceptual functions, self-control or self-regulation and executive functions (EF). EF are cognitive processes that are necessary to achieve a defined goal. These functions represent a series of sub-processes that have different tasks and effects such as anticipating, decision making, inhibitory control, working memory and creativity.[8,9] In the context of sports with a game character, athletes need to use both basic and higher cognitive functions to read and react to certain situations and game patterns.[10,11] According to these definitions, ice hockey can be classified as a strategic, open-skill sport game because the game environment changes rapidly and players have to adapt to these changes in a very short time using a high level of cognitive function. In addition, ice hockey players perceive the changing, unpredictable and externally controlled environment through sensory cues, such as vision and their ability to see the ice and scan for open lanes when on offense or read the attack coming when on defense, their hearing of calls by team members, opponents or referees and their sense of feeling pressure from an opponent close to them, such as when they have the puck on their stick.[12] They must be able to recognise and process situations as quickly as possible and filter out and implement the optimal or most effective decision among all the possibilities.[4,13] The exceptional ability to read and react to certain situations on the ice is what separates elite players from others.[2,14] Various studies conducted in the sport of soccer have illustrated that individual success in game situations and the solution of game-specific problems are related to EF. Accordingly, players with more developed EF have more success in different game situations than players whose EF are less developed.[15-17] Thus, EF are an essential component of the cognitive performance of athletes in diverse game sports and show high correlations to individual success in the game.[13,18,19] Consequently, it can be assumed that, in addition to physical characteristics such as body height, weight or muscle fibre composition, psychological characteristics such as cognitive functions are directly related to the performance a player achieves in competition.[15-17]

Interceptive sports such as soccer, handball or ice hockey have a complex physical and psychological stress profile.[6] In addition to the distinct physical stress profile, a variety of psychological, cognitive functions are part of a player's qualities.[6,20] Many of the performance characteristics are not clearly measurable. Therefore, the qualities of an athlete have to be considered subjectively. A particularly important characteristic for the performance of players in open skill-interceptive sports is game intelligence.[6,21] In sports science, the term game intelligence refers to the optimal solution of game-specific problems in individual, group and team tactical situations.[10,22,23] Game intelligence is captured through observations by coaches and talent scouts, who investigate players over a long period of time for accurate assessment. The evaluation of this performance component is associated with a very high expenditure of time and very close observation of the player.[24] There are no general indicators, criteria, guidelines or target values for the evaluation that experts can use as orientation. Coaches and talent scouts establish criteria according to their own expertise and judge according to these when observing a player. Based on the demands and situations a player is exposed to during a match however, game intelligence can be captured through different cognitive functions.[6] Thus, game intelligence can be expressed through specific EF such as cognitive flexibility, working memory and creativity. Therefore, it can be assumed that the ability to find solutions to sport- or game-specific problems in different situations is related to a player's EF.[13,15,16,19,25] More recently, there are several articles that have demonstrated a relationship between EF and performance in competition.[13,16,25] Vestberg et al.[16] investigated EF in soccer players (n = 30; mean age 14.93 years). The authors found a significant positive correlation ($r = 0.349$; $p = 0.29$) between performance (i.e. goals and assists in the game over a two-year period) and cognitive performance measured by the Design Fluency Test (DFT) in the soccer players tested. Sakamoto et al.[13] measured significantly higher EF scores ($d = 0.31$; $p = 0.003$) in Japanese youth soccer players (n = 383, mean age 9.7) of higher, compared to lower soccer performance.

Furthermore, Lundgren et al.[6] did not establish any correlation between expert rated game intelligence (>10 matches rated) or personal player statistics of one season and EF, which was measured by Trail Making Test (TMT) and DFT, in Swedish professional ice hockey players (n = 48, mean age 23.7). Lundgren et al.[6] summarises that EF testing can differentiate important cognitive functions related to ice hockey, however more research is needed to unambiguously determine successful ice hockey players. Accordingly, further studies are needed before psychological testing procedures of this kind can be applied in regular sport practice.[18] This serves as a rationale for this paper, which will be based on the procedures of Lundgren et al.[6] The same psychological assessments that have been used in previous work by Vestberg et al.[15,16] and Lundgren et al.[6] will be applied.

When measuring sports performance traditional approaches use scoring indicators such as goals, baskets, assists, turnovers, to name a few, which are typically recorded in a discrete sequential manner to describe general sports behaviour or technical performance.[26] Although in complex situations, involving many different cognitive and environmental factors this method alone is considered outdated.[27] To address these elements, the ecological dynamics approach helps assessing game performance which involves the relation between the performer and its complex environment.[28] Due to the dynamic environment and the rapid change of situations the analysis contains the consideration of surrounding constraints (e.g. location of opponents, team-mates, referees, goals, location of the object of play, lanes for passing or shooting, etc.).[26,29] The aforementioned studies[26,27,29] suggest considering both approaches to provide a precise way of analysing game intelligence. For this purpose, the Game Performance Assessment Instrument (GPAI) was selected, which is able to measure tactical-cognitive performance in competitive sports.[19,30] Thus, the extent to which there is a correlation between the

EF measured outside the ice and game intelligence determined in the game is examined.

The results of this study may provide initial insights into the contribution of EF to game intelligence of ice hockey players and whether psychological testing procedures could be suitable for determining game intelligence. Hence, the study's objective is to investigate the correlation between EF and game intelligence, thereby verifying the possibility of EF as a performance prediction tool for game intelligence. If the assessment of EF is a major predictor, practice to increase the EF may help improve performance and include the assessment of EF in the player selection criteria and talent identification, making it possible to detect excellent players.[2] According to previous work by Vestberg et al.[16] and Sakamoto et al.,[13] there are correlations between the EF and the in-game ability to solve specific problems. Both studies determined the EF of youth soccer players using psychological assessments. However, the authors did not examine any correlations between EF and game intelligence, and instead used personal statistics such as goals and assists in a season,[16] as well as successful acceptance into an elite youth program of a Japanese football club[13] as an outcome. Both studies found significant results, according to which higher scores in EF correlated with more goals or assists,[16] as well as selection for the elite youth programme.[13] Thus, it can be concluded that there are positive correlations between a player's general EF and athletic performance. Therefore, the current study therefore aims to investigate the relationship between EF and game intelligence as a cognitive parameter of athletic performance. Due to the similarities between the sports of soccer and ice hockey, such as focusing on the object of play, the ball or puck, movement patterns of teammates and opponents, information absorption, adaptation to constantly changing situations and decision-making as a solution to different situations, similar results are expected as those already found in previous studies[6-8] in soccer. Therefore, we hypothesised that measures of EF will be positively related to game intelligence.

MATERIAL AND METHODS

PARTICIPANTS

A field study was conducted in which ten male subjects (mean age: 17.3 ± 1.0 years; body mass: 77.4 ± 4.9 kg; body height: 182.6 ± 3.9 cm) from a junior ice hockey team of the highest junior league in Germany, were randomly selected from the overall team. Participants had six training sessions on the ice and four off the ice in a regular training week. Depending on the match schedule, training is accompanied by matches at the weekend. The players and parents of a team of 26 were asked to participate, whereupon 15 agreed to take part in the further data collection. Agreement of anonymous dissemination of data for research purposes (publication) was agreed by the host club. Both the players and their legal guardians were informed about the testing procedures, risks and benefits and signed a written informed consent form. Goalkeepers were not included in the study, as the requirement profile of goalkeepers differs significantly from that of field players.[31] Another exclusion criteria from the study were mental illness, playing experience of less than five years, and current injuries preventing participation in competitions during the evaluation period. Players who stated that they had already suffered several injuries to the nervous system in childhood or adolescence, such as a traumatic brain injury in the form of a concussion, were also excluded from the study. Of the 15 players selected, five had to be excluded from the study because they either reported suffering a concussion prior to the study, got ill or injured during the observation period or were not on the playing roster for different reasons for one or more of the recorded games. Therefore, the final test group consisted of ten players (mean age: 17.3, SD: ±1.0 years) which had different playing positions and were both attackers (centers and wingers) and defenders. Due to the sample size, no further statistical testing procedures could be used to examine differences in the various playing positions.

PROCEDURES

The study was conducted during the specific pre-season period. The testing procedures to determine EF were conducted off the ice, two weeks after the start of training. A standardised test procedure and environmental conditions were determined for the psychological measures. As part of the preparation for the test, a quiet and bright room was selected and the number of possible interfering factors, such as external stress due to acute strains, was minimised in advance. The test subjects completed the test procedures at the same time of day, the same room, in the afternoon before the start of the ice training at their teams' training facility. Subjects were also required to have at least eight hours of restful sleep the night before, which was confirmed verbally before testing. The players were tested on their EF (August 2022). Prospective data collected by the analysis of games was used (August-September 2022) to study whether TMT or DFT scores correlate with the game intelligence of the ice hockey players tested before.

MEASURES OF EXECUTIVE FUNCTIONS

The selection of the test procedures for determining the EF was based on various papers prior to this study.[6] The testing of the Delis-Kaplan-Executive Functioning System (D-KEFS)[32] form the basis for the development of EF. The D-KEFS is considered to be a comprehensive compilation of several subtests for the assessment of primary neuropsychological abilities such as perception, attention and language. The D-KEFS test procedures also ensured the valid and reliable examination of higher cognitive processes such as problem solving, cognitive flexibility and abstract, logical thinking.[33,34] D-KEFS is an innovative and promising instrument for measuring EF for both clinical and non-clinical populations.[35] In addition, the D-KEFS test procedures are designed to cover a broader range of functioning than other psychological test procedures for determining EF, making it possible to assess and differentiate individuals with excellent executive functioning.[35,36] The parameters used in task solving are the time taken to complete a task and the accuracy or correctness of the solutions. Standard errors of measurement and confidence intervals were estimated for both the D-KEFS tests and the GPAI. All of these tests demonstrated that the battery testing procedures are valid methods for studying EF[32] and that the GPAI is a valid instrument to measure game intelligence and its components. The outcomes are shown in the results section. The test procedures carried out include TMT and DFT.[32] In order to get familiar with the test requirements the subjects had the opportunity to complete a sample task of both the TMT and the DFT.

TRAIL MAKING TEST

To solve TMT and therefore measure trail making (TM) performance, subjects are required to connect letters and numbers in alphabetical and numerical order as quickly and flawlessly as possible. The letters and numbers are spread out on the sheet so that the test persons are forced to look over the entire sheet in order to decide on the correct letter or number in a short time. The tasks vary from connecting letters to numbers and then alternating letter-numbers. Cognitive flexibility is associated with the ability to switch back and forth between different tasks. TMT thus assesses visual-motor sequencing and cognitive adaptation to varying tasks. In sports such as basketball, football and ice hockey, which have an "open-skill" character, cognitive adaptation to situations is necessary. Game situations change frequently and abruptly and players are subject to cognitive load such as spatial perception and the associated processing of information about teammates, opponents and the location of the ball or puck.[11] For this reason, the TMT contrast score of number-letter switching (TMT-condition 4) vs. visual scanning (TMT-condition 1) was selected as it has been shown to examine visual scanning, visual-motor sequencing and cognitive flexibility.[37]

DESIGN FLUENCY TEST

For DFT,[32] dots framed in a square are to be connected with a pencil. A time limit of 60 seconds is set for each task. As many different designs as possible are to be created in this time. Using the same solution is not allowed and will therefore not be scored. In the first task, as many designs as possible are to be created by connecting the filled dots. In the second condition, unfilled dots are added. The task is similar to the first condition, however in this version the subjects connect the unfilled dots together. Although the filled dots are still present, the subjects are not allowed to use them. In the third condition, both the filled and unfilled dots are to be used. alternating between them. Design fluency (DF) performance is measured by a non-verbal task that assesses the following executive functions: Initiation (of problem solving), Fluency (in generating visual patterns), Creativity (in drawing new designs), Concurrent Processing (drawing designs while following rules and constraints) and Inhibition (of previously drawn designs). DFT was deliberately chosen for the study because it includes a creative element,[32] which is considered to be important in team sports.[38,39] Another advantage of DFT is that it is largely dependent on visual scanning ability.[40] The test scenario is comparable to an ice hockey game as participants (a) are under time pressure, (b) have to scan the field, (c) have to distinguish between relevant and irrelevant stimuli and (d) have to make quick decisions while being creative within set limits. Subjects must use and constantly update their working memory to remember which designs have already been used. Thus, DF engages the basic EF working memory, inhibition and creativity.[17,18,33] We chose the DFT because the EF measured are significantly involved in problem solving and decision making in complex sporting situations and is thus directly related to game intelligence.[10]

MEASURES OF GAME INTELLIGENCE

Game intelligence was evaluated by analysing four matches. The matches were recorded by video camera (Sony FDR AX43A, Sony Group Corporation, Tokyo, Japan) and evaluated individually for each player who participated in the study. The assessor had five years coaching experience at sub-elite youth level and five years playing experience in competitive ice hockey. The GPAI assesses individual tactical-cognitive reasoning in both offensive and defensive game situations.[30,41-43] Since the GPAI has only been used to characterise game intelligence in other sports such as soccer[19] or volleyball,[18] ice hockey-specific parameters had to be established for the GPAI. Accordingly, individual tactical behaviour was assessed by decisions with and without the puck in both defensive and offensive situations (Decision Making Index) and technical executions such as pass receiving and pass giving or shooting (Skill Execution Index) were assessed. In addition, the game without the puck was assessed in order to evaluate the skills in these game situations. When the team was in possession of the puck, for example, the positional play in the build-up to the game or in attacking plays was evaluated, in which the players had to put themselves in an optimal position to support the puck leader in the attack. Furthermore, situations were analysed in which teammates needed support in a duel in order to win the duel and win back the puck (Support Index). The evaluation of the three sub-parameters finally resulted in the calculation of the total game intelligence.[30]

STATISTICAL ANALYSIS

All statistical analyses were performed using IBM SPSS Statistics software (version: 28.0.1.1). For all calculations, the significance level was set at $p < 0.05$. Normality was checked for all variables by the Shapiro-Wilk test. The Shapiro Wilk test showed a significance greater than 0.05 for all variables, meaning that the variables were normally distributed. The exception was the results of the DFT. The Shapiro Wilk test indicated a significance of less than 0.05 for the variable DF test results, which indicated that the variable was not normally distributed. Both dependent and independent variables were checked for outliers using boxplots. No outliers could be detected on the figures.

	n=10			
Variable	M	SD	95% CI	SE
Trail Making	9.3	2.5	[11.1, 7.5]	.79
Design Fluency	15.0	3.1	[17.2, 12.8]	.99
Skill execution	2.1	.62	[2.6, 1.7]	.19
Decision making	1.9	.74	[2.4, 1.4]	.23
Support	2.3	.73	[2.8, 1.7]	.23
Game intelligence	2.1	.6	[2.5, 1.7]	.19

Table 1. Descriptive statistics of the variables used to assess executive functions and game intelligence.

Note. M and SD are used to represent mean and standard deviation, respectively. Values in brackets indicate the lower and upper limit of a CI, confidence interval.

Correlations were calculated to show the direct relationships between dependent variable game intelligence and independent variables TM and DF. Accordingly, the Pearson coefficient was used for normally distributed variables and the Spearman Rho coefficient was used to calculate relationships that included the non-normally distributed variable (DF). To examine the influence of the independent variables TM and DF on the dependent variable game intelligence we carried out a multiple linear regression. It was ensured that the requirements for the multiple linear regression model autocorrelation, no outliers, homoscedasticity and linearity were met. Further a Tukey's post-hoc adjustment was performed to reduce the risk for type-I-errors.[44] When interpreting the correlation results, the standard values for effect sizes according to Cohen[45] were taken into account. Accordingly, a correlation coefficient (r) of 0.10 to 0.29 is regarded as weak, 0.30 to 0.49 as medium and 0.50 and above as strong. Importantly, DF was used as our main analysis, as it was the one of the D-KEFS tests containing factors we believe are most important in ice hockey (fast creativity or problem-solving abilities). We reported the empirical F value to represent how much of the variance can be explained by the variable.

RESULTS

The experiment in this study was designed to investigate the relationships between higher cognitive functions and game intelligence of ice hockey players. The means and standard deviations of the results of both psychological testing and the assessment of game intelligence and its components are shown in Table 1.

Correlations between the variables results of the EF assessments, the sub parameters of game intelligence and overall game intelligence are shown in Table 2.

The correlation analysis shows a strong positive highly significant correlation between TM and the sub-parameter support index (SI) (r = 0.68, p = 0.008). In addition to the correlation with the sub-parameter SI, the determined TM correlates strongly positively (r = 0.683, p = 0.029) with the overall game intelligence. The results of the correlation analysis for the relationships between the variables TM (A), DF (B) and game intelligence are shown in Figure 1.

In addition to examining the statistical correlations between the EF and the game intelligence, further correlations were sought between the variables age, playing experience and the game intelligence. The analysis for the correlations between the variable age and the parameters of the game intelligence shows a strong positive significant correlation between age and the execution index, which can be understood as a technical component (r=0.64, p=0.045). No further significant correlations were found for the age variable with game intelligence or the other sub-parameters. Similarly, no significant correlations were found for the sub parameters and the overall game intelligence for playing experience, the time in years that players have been active in the sport.

A multiple linear regression was carried out to determine the influence of individual variables on game intelligence. The Durbin-Watson test was performed to check for autocorrelation. The values for all variables included in the regression were around the value 2, which suggests that there are no first-degree autocorrelations. Furthermore, casewise diagnostics were used to check for outliers. No outliers were detected for any of the variables used in the regression. In order to examine homoscedasticity, the scatter diagrams were considered for the distribution of the values in the diagram. Partial regression plots were used to check whether the linearity requirement was met. A curved relationship was not found for any of the variables, which means that linearity between the variables exists.

The ANOVA model showed no significant effect for TMT scores (F = 2.81, p = 0.13) on overall game intelligence.

For the correlation between DF and game intelligence, a medium positive non-significant relationship (r = 0.330, p = 0.352) was found. Furthermore, DF did not correlate with any of the sub-parameters. For DF the ANOVA model again showed no significant effect (F = 1.248, p = 0.43) on overall game intelligence.

DISCUSSION

The study aimed to investigate the relationship between EF and game intelligence as a cognitive parameter of athletic performance. Findings results suggest that TM is closely related to game intelligence, as TMT results correlate

	Skill execution	Decision making	Support	Game intelligence
Age	.64* (.81)	.29 (.31)	.17 (.17)	.42 (45)
Playing experience	-.26 (-.27)	-.082 (-.82)	-.34 (-.36)	-.25 (-.26)
Trail Making	.22 (.23)	.2 (.21)	.68** (.84)	.68* (.82)
Design Fluency	.46 (.42)	-.04 (-.08)	.36 (.23)	.33 (.27)

Table 2. Correlation matrix for all variables identified.

Note. For the correlation analysis with the variable Design Fluency, the Spearman Rho correlation was calculated because the results of the DFT are not normally distributed. The first value indicates the correlation coefficient of Pearson and Spearman, while the value in the bracket indicates the effect size of Fisher's z. * indicates p < 0.05, ** indicates p < 0.01.

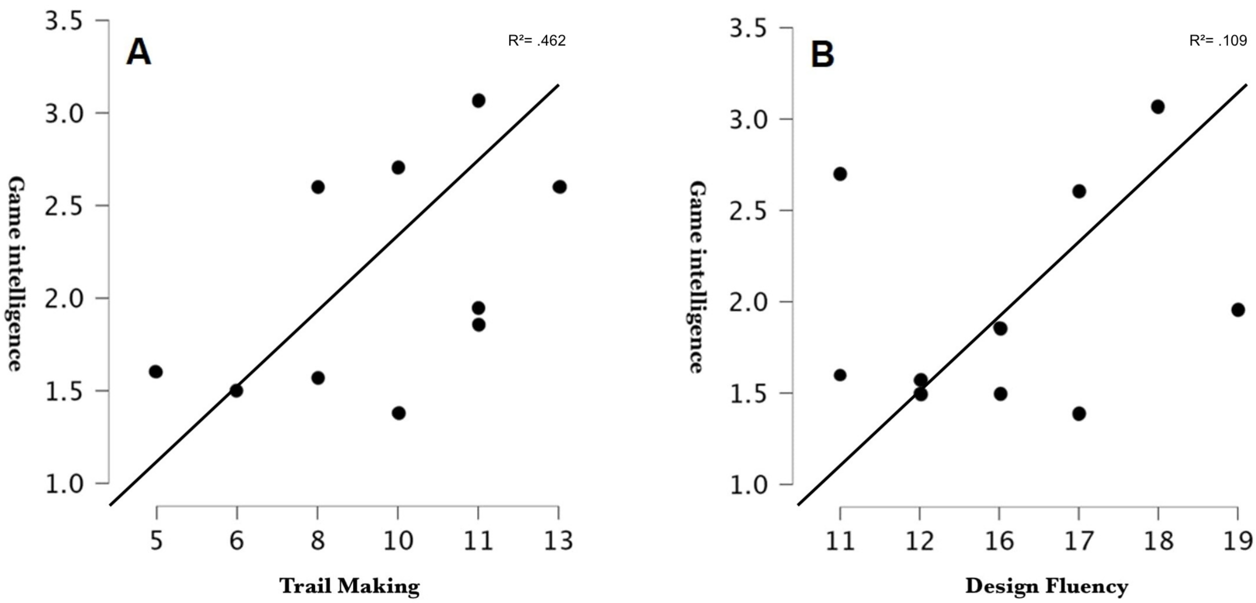

Figure 1. Relationship between trail making (a), design fluency (b) and game intelligence.

strongly with the in-game support index parameter and the overall game intelligence. The TMT provides detailed information about visual motor processing and speed. The test gives additional information about impulsivity and flexibility of thinking in nonverbal problem solving.[35] TMT is to some extent a verbal test and therefore, its results could be affected by educational background. If a player has low verbal skills, it may has a negative impact on his TMT score.[6] Additionally, there was a significant positive correlation between EF as assessed with the TMT and game intelligence but given the small sample size, one cannot assume general causality. In contrast the second test conducted, the DFT is a nonverbal test and the EF taped include initiation of problem-solving behavior, fluency in generating visual patterns, creativity in drawing new designs, simultaneous processing in drawing the designs while observing the rules and restrictions of the task, inhibiting previously drawn responses and remembering what was drawn using ones working memory.[35] It was assumed that EF such as creativity, inhibition and planning or deciding actions, represented by the DFT, correlate with game intelligence. Although DF is more relevant in representing the EF that players rely on in team sports compared to TM,[6,18] there were no correlations found. The reason could be the low transferability of conventional test procedures to the actual competition situation combined with the complex demands to which ice hockey players are exposed.[6,46]

Positive correlations between the results of psychological tests such as TMT or DFT and personal statistics such as goal and assist rates have already been established in several studies.[15,16,25] According to these studies, a player's EF correlated positively with the goals he scored in a season. In another study by Heilmann et al.,[19] positive correlations were found between the EF inhibition of elite junior soccer players and game intelligence measured by GPAI. In ice hockey, however, a similar study design was used for the first time by Lundgren et al.[6] The authors concluded that EF are an important component of the cognitive performance of ice hockey players but could not prove this with sufficiently representative results. They conducted TMT and DFT with professional ice hockey players from the Swedish 1st and 2nd leagues and to assess game intelligence, the authors used ice hockey experts who were asked to give their assessment of a player's game intelligence on a scale of 1-10. The assessment was thus very subjective and not based on a valid and reliable measurement tool. The results obtained provided partial positive correlations between the EF and game intelligence assessed. Significant positive correlations between EF and game intelligence could already be established in soccer.[13,15,16,19] Despite the study design being similar to that of previous studies conducted in soccer,[13,15,16,19] our study could not confirm these results. A possible explanation for these divergent results could be that soccer, while also having an "open skill character", differ from ice hockey in terms of the playing field, the surface, the number of players and the general game dynamics.[6] Another important consideration is that sport-specific cognitive functions are developed in sport-related contexts such as training and competitive conditions. Therefore it is possible that only the examination in natural environments is applicable and the assessment should not be determined by general measures such as psychological assessments.[46] The results of our study showed that there is a possibility that athletes can be successful and perform well in tests and thus show pronounced EF off the ice, but not be successful in more complex sport-specific tasks because the demands of competition differ too much from the test situation. Our findings deliver some limited support for the prospective power of the EF testing conducted. Due to the above-mentioned reasons, it remains uncertain what significance off-ice EF have for game intelligence and whether they can really be properly attributed to it.

LIMITATIONS

The tasks that were processed in the test procedures differ from the demands that players are exposed to during a game. While the test procedures were conducted under standardised conditions, the game on the ice is spontaneous and subject to many influencing factors. Factors such as general volition, general state of mind or health, emotions, score, behaviour of teammates and opponents or team tactical instructions by the coach can influence the parameters measured by the GPAI. When investigating game intelligence, future research should implement the ecological dynamics approach in addition to the indicators of GPAI, as this proposes performer-environment relationships to fully understand sport performance. To elucidate the emergence of interactions between players and their environment, the ecological dynamics approach should be considered when measuring game intelligence in team sports. Another limitation is the small amount of video material. Only four matches were recorded and therefore could be analysed. The evaluation of game intelligence requires the analysis of many games over a long period of time to capture specific on ice cognitive functions. Furthermore, to the authors' knowledge, the GPAI has not yet been used in ice hockey and no inter-observer reliability assessment has been performed.

Another limitation of this study is the sample size, which, due to practical constraints, comprised of ten players from a German junior ice hockey team. A post-hoc power analysis was conducted to evaluate the statistical power of the study, considering the actual sample size. This analysis, informed by two previous studies,[25,47] which identified a moderate correlation (r = 0.37; 0.30) between Design Fluency and coach-rated game intelligence, indicated that the sample size of ten yields a power ($1 - \beta$) close to 80% for detecting similar effect sizes, with a significance level set at 0.05[45]. It is important to note that accessing elite youth samples can be challenging, and the study successfully engaged as many participants from the club as were available in this age group. While the results provide meaningful insights, the post-hoc power analysis suggests that larger samples would be beneficial in future research to increase the statistical power and further validate the findings. This limitation underscores the need for cautious interpretation of the study's outcomes and serves as an impetus for future studies to explore similar relationships with larger sample sizes in elite youth sports settings.

CONCLUSIONS

The results of the current study show that EF and game intelligence are partially related, but no general correlation can be established. The results of this study do not completely support the assertion that the assessment of EF by the use of psychological testing should be a part of the evaluation of ice hockey players. That said, studies showed that EF are significantly involved in the success in many situations in an ice hockey game. For this reason, EF's should be considered when assessing a player's game intelligence however given the results of this study EF may have to be assessed through a different approach. The development of basic and higher cognitive functions should be considered in the long-term athletic development of a player. In addition to the training of hockey-specific skating, shooting, passing and tackling techniques, interventions should increasingly aim to develop players' cognitive functions in drills and games in order to improve specific game intelligence. Further research should include the assessment of EF regarding individual playing positions to determine position-specific cognitive characteristics. Larger samples with players from different positions and different playing or age groups would contribute to the general understanding of EF in hockey and the relationships between EF and game intelligence. Further studies would make it possible to formulate more precise statements on the general relationship between EF and the player profile.

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CONFLICTS OF INTEREST / COMPETING INTERESTS

The authors declare that they have no competing interests.

AVAILABILITY OF DATA AND MATERIAL

The original contributions presented in the study are available for the general public. Inquiries can be directed to the corresponding author/s.

AUTHORS' CONTRIBUTIONS

Conceptualisation: P.B. and M.N.; methodology: P.B. and M.N.; formal analysis: P.B. and M.N.; writing—original draft preparation: P.B. and M.N.; writing—review and editing: P.B. and M.N. All authors discussed the results and contributed to the final manuscript.

ETHICS APPROVAL

Approval for the study protocol was obtained from the Human Ethics Committee at the Nordic Science Institute of Biomechanics and Neurosciences, Hannover, Germany.

CONSENT TO PARTICIPATE

Both the players and their legal guardians were informed about the testing procedures, risks and benefits and signed a written informed consent form.

CONSENT FOR PUBLICATION

Agreement of anonymous dissemination of data for research purposes (publication) was agreed by the host club.

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