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ANALYZING MULTIPLE OBJECT TRACKING ACCURACY IN ICE HOCKEY PLAYERS 13–15 YEARS OLD

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Факторы точности слежения за движущимися объектами у хоккеистов 13–15 лет

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Abstract

The multiple object tracking task is extensively utilized to assess athletes in team sports, such as hockey, due to its relevance to real-game scenarios involving the tracking of partners and opponents. Typically, task difficulty is evaluated based on the number of objects and motion speed; however, the impact of additional parameters on athletes' tracking accuracy has been largely overlooked. The aim of the current study is to investigate the relationship between the accuracy of a three-dimensional multiple object tracking task and the task parameters, as well as the playing positions of field ice hockey players aged 13 to 15 years. A total of 29 forwards

Резюме

Задача слежения за движущимися объектами широко используется при тестировании спортсменов командных игровых видов спорта, таких как хоккей, из-за схожести с игровыми ситуациями, включающими отслеживание партнеров и соперников. Как правило, сложность задачи задается количеством объектов и скоростью их движения; при этом влияние других параметров задачи на точность зачастую не рассматривается. Цель исследования — изучение взаимосвязи точности слежения за движущимися объектами в трехмерном пространстве с параметрами задачи и игровым амплуа хоккеистов 13–15 лет. 29 нападающих и 20 защитников выполняли задачу слежения за движущимися объектами в виртуальной

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and 20 defensemen participated in a virtual reality-based three-dimensional multiple object tracking task. Key metrics recorded included task accuracy, total path length of objects, number of collisions, number of occlusions, and motion speed of the objects. A generalized linear mixed model analysis revealed that motion speed and the frequency of occlusions caused by distractors obscuring the target negatively impacted tracking accuracy. This finding highlights the necessity of incorporating various task parameters in the applied assessment of athletes. Moreover, no significant relationship was found between multiple object tracking performance and the playing positions of adolescent hockey players when controlling for task parameters. This indicates a need for domain-specific testing of athletes and suggests future comparisons involving adult athletes across different playing positions.

Keywords: sport, ice hockey, multiple object tracking, attention, accuracy, virtual reality.

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реальности. Регистрировались параметры выполнения задачи: общая длина пути объектов, количество столкновений, количество перекрытий, скорость движения объектов, а также точность отслеживания. Анализ с использованием обобщенных линейных моделей со смешанными эффектами показал, что скорость движения и частота перекрытий, в которых дистрактор закрывает целевой объект, отрицательно связаны с точностью отслеживания. Результаты указывают на значимость учета различных параметров задачи в тестированиях спортсменов. Кроме того, не было выявлено значимой взаимосвязи между точностью слежения за движущимися объектами и игровым амплуа хоккеистов-подростков при учете параметров задачи. Это свидетельствует о важности использования более специфических для спорта когнитивных тестов и необходимости дальнейших исследований с участием взрослых спортсменов разных амплуа.

Ключевые слова: спорт, хоккей, слежение за движущимися объектами, внимание, точность, виртуальная реальность.

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Perceptual-cognitive abilities are essential for athletes participating in team sports, as players must continuously perceive and analyze information to make informed decisions that enhance effective interaction within a dynamic game environment (Scharfen & Memmert, 2019). Research on perceptual-cognitive expertise in sports typically employs two main approaches. The first is the expert-performance approach, which investigates athletes within sport-specific or ecologically valid contexts by integrating key elements of the sport into the experimental design — such as the presentation of stimuli and the nature of responses (Starkes & Ericsson, 2003). Findings derived from this approach have consistently indicated

that experts outperform novices in perceiving and responding to sport-relevant signals (Kalén et al., 2021; Mann et al., 2007).

An alternative methodology, known as the cognitive component skill approach, examines the correlation between domain-general cognitive functions and athletic performance. Within this framework, cognitive functions are typically assessed through standardized cognitive assessments that provide context-independent information (Scharfen & Memmert, 2019; Voss et al., 2010). The theoretical assumption underlying this approach suggests that a prolonged engagement in team sports that require significant perceptual-cognitive abilities, leads to extensive alterations in cognitive functions which are evident even in tasks unrelated to a particular sport (Scharfen & Memmert, 2019; Voss et al., 2010).

One of the most challenging perceptual-cognitive requirements for athletes engaged in team sports is the ability to monitor the position of the ball (puck) while simultaneously tracking the movements of both teammates and opponents (Faubert, 2013). These requirements are comparable to the cognitive demands of the multiple object tracking (MOT) task, a cognitive paradigm where participants track multiple moving targets among visually similar distractors (Meyerhoff et al., 2017; Pylyshyn & Storm, 1988). Given that MOT is a perceptual-cognitive ability acquired through experience in dynamic sporting contexts, researchers are interested in assessing MOT differences between expert athletes, less skilled athletes and non-sporting population. Comparative studies generally indicate that athletes engaged in team sports exhibit performance advantages over non-athletic individuals (Howard et al., 2018; Jin et al., 2023; Wierzbicki et al., 2024). Furthermore, high-level athletes in ice hockey (Zhang et al., 2021), soccer (Jin et al., 2023), and basketball (Gou & Li, 2023) have been shown to possess superior accuracy in MOT when compared to lower-level athletes. Nevertheless, these findings have not been entirely consistent (Styrkowiec et al., 2024; Su et al., 2024). A recent meta-analysis suggests that athletes with varying levels of sports experience consistently outperform non-athletes, with notable differences observed between expert and novice athletes (Liu et al., 2024).

Although a relationship between MOT accuracy and athlete skill has been identified, the specific nature of this relationship remains unclear (Harris et al., 2020; Mackenzie et al., 2024). In discussing the mechanisms that contribute to the advantages, authors frequently provide ambiguous explanations, such as the transfer effects of training (e.g., Harris et al., 2020; Mackenzie et al., 2024) or the implications of selection processes (Jin et al., 2020; Howard et al., 2018).

The lack of a comprehensive understanding regarding the nature of the athletes' advantage in MOT may stem from the ambiguity surrounding the fundamental mechanisms underlying MOT. A primary question remains regarding how objects are associated with their mental representations, as well as how information regarding changes in location is updated during the tracking process (Holcombe, 2023). Current knowledge indicates that attention, potentially facilitated by spatial working memory, plays a critical role in enabling MOT (Holcombe, 2023; Merkel et al., 2022; Tombu & Seiffert, 2008; Holcombe & Chen, 2013). Furthermore, the capacity to group objects has been identified (Yantis, 1992), with

distinct processes observed in the two hemispheres that independently process information from hemifields (Merkel et al., 2024). The ongoing debate regarding whether information about objects is updated serially or in parallel continues (Holcombe, 2023; Holcombe & Chen, 2013), with evidence suggesting that both mechanisms may interact with one another (Holcombe, 2023; Meyerhoff et al., 2017). Additionally, research supporting the flexibly allocated tracking mechanisms (Alvarez & Franconeri, 2007) indicates that participants allocate their attention to regions or objects that are at the highest risk of being overlooked due to a high number of objects within a small space. The handling of object occlusions (Kamkar et al., 2020), collisions, and groupings (Vater et al., 2017) has a substantial impact on tracking accuracy, as saccades directed towards these areas result in the suppression of information processing (Hyönä et al., 2019).

Despite evidence from studies on visual perception and attention indicating that the specified task parameters significantly influence the accuracy of tracking, their consideration in research involving athletes remains limited. The tasks employed in applied studies typically account for the speed of object movement and the number of objects (Liu et al., 2024). However, interindividual variability may be partially associated with individuals' abilities to resolve object occlusions, collisions or other task parameters related to object spacing.

Additionally, research in sports science does not consider the playing position of athletes when investigating cognitive functions. While several studies have categorized goalkeepers as a distinct group, the differentiation among field players is notably infrequent, and the sample sizes utilized are often limited (Lundgren et al., 2016; Wimshurst et al., 2012). However, game requirements associated with forwards and defensemen exhibit significant differences (Vigh-Larsen & Mohr, 2024; Wimshurst et al., 2012), which are reflected in their skills and physical conditioning (Bournival et al., 2023; Daigle et al., 2022). Forwards must excel at evading defensemen while identifying optimal positions for puck reception and goal shooting. In contrast, defensemen are responsible for playing the attackers, necessitating a division of attention to maintain positional awareness relative to the goal while simultaneously monitoring the puck. Although essential for all players, this divided attention is particularly crucial for defensemen, who must maintain a comprehensive view of the ice surface to anticipate offensive maneuvers and devise counterattacks (Johnston & Walter, 2018). Therefore, based on these positional distinctions, it can be hypothesized that hockey defensemen will demonstrate higher accuracy rates in MOT compared to forwards.

Thus, the aim of the current study is to investigate the relationship between the accuracy of a three-dimensional (3D) multiple object tracking task and the task parameters, as well as the playing positions of adolescent field ice hockey players. In this context, task parameters are defined as the motion speed of objects, the distance traveled by objects, and the frequency of occlusions and collisions (both among objects and with boundaries). By considering these parameters, this study aims to enhance understanding of their impact on task performance in 3D space – a condition increasingly utilized in applied testing but one that has been less thoroughly examined in terms of tracking specifics.

Methods

Participants

A total of 49 young hockey players (29 forwards and 20 defensemen) were recruited for this study. The participants represented ten teams competing in the Russian Championship for athletes under 15 years of age. The cohort consisted of male athletes aged 13 to 15 years, with a mean age of M(SD) = 14.50 (0.30). Participants had 6 to 10 years of organized hockey experience and engaged in 12 to 20 hours of training per week, with a mean of M(SD) = 15.60 (2.36) during the year before testing (conducted in January 2023). All participants had normal or corrected-to-normal vision and reported no history of brain trauma or mental illness. Written informed consent was obtained from their parents prior to participation. The experimental protocol was approved by the ethics committee of Sirius University.

3D Multiple Object Tracking task

The 3D MOT task was implemented using the VR Head Mounted Display (VR-HMD) HTC VIVE Pro Eye. The environment was developed utilizing the Unity 3D game engine (version 2019.2), with SRanipal Runtime employed to interface the MOT paradigm. Observers utilized an HTC Vive Controller to identify the objects requiring tracking and to initiate new levels.

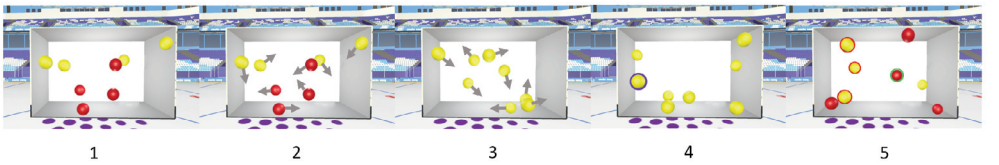
The participants completed the MOT task individually. Assessments were conducted in the same room at the testing facility with a standardized familiarization protocol. The participants were seated in a stationary chair and reported a comfortable VR-HMD position. Prior to the main task, the participants received instructions and engaged in one practice trial. All the participants completed the practice trial with a 100% accuracy, allowing us to limit the training to a single level.

The total duration of the task was approximately five minutes, comprising 15 control levels. Each level consisted of five standard phases (figure 1): (1) an array of four yellow distractor balls and four red target balls was presented within the VR space; (2) a participant initiated the motion of the balls by pressing a button on the controller; (3) four seconds thereafter, all target balls were rendered indistinguishable from the distractors; (4) eight seconds thereafter, the movement stopped, and the participant identified the targets by pointing at and selecting them with the controller; (5) a feedback was provided after the selection, highlighting correctly identified targets in green and incorrectly identified targets in red. Following the feedback, the participant initiated the next trial. The total duration of each trial was 12 seconds, in addition to the selection time. There were no time restrictions imposed on either the selection phase or the initiation of motion. The participants were permitted to move their eyes and heads freely throughout the entire task.

The initial speed of the balls was set at 1 m/s. If all four balls were accurately identified in a given stage, the speed for the subsequent stage was increased by 0.2 m/s; otherwise, it remained unchanged. The dimensions of the 3D environment

Figure 1

Five Phases of the Object Tracking Task



(1) an array of four yellow distractor balls and four red target balls is presented; (2) the participant initiates the motion of the balls; (3) four seconds thereafter, all target balls are rendered indistinguishable from the distractors; (4) eight seconds thereafter, the movement stops, and the participant identifies the targets; (5) a feedback is provided after selection.

were 3.5 m (length) × 2.2 m (height) × 1.5 m (depth), positioned 3.8 m forward and 1 m above the center of the virtual space established during the SteamVR room setup. The front wall was transparent, while the remaining walls were gray. The background of the room was designed to resemble a hockey court. The initial positions of the objects were randomly determined, with a constraint ensuring a minimum inter-object distance equivalent to one ball diameter. The initial movement direction for each ball was randomized. Collisions between objects were absolutely elastic; however, if any ball encountered multiple collisions within a period of five frames, that ball was subsequently moved in a random direction to prevent overcrowding.

The accuracy of task performance, quantified by the number of correct responses (ranging from 0 to 4), was recorded at each level. Additionally, variables related to task parameters were recorded. Table 1 presents the list of task parameters along with their mean values for all levels and participants.

Table 1

Multiple Object Tracking Task Parameters

Task parameter	Value (M ± SD)
Motion speed of objects, m/s	1.6 ± 0.36
Path length of all objects, m	179.16 ± 42.36
Path length of targets, m	89.27 ± 21.04
Collisions of all objects with walls, n	159.39 ± 37.77
Collisions of targets with walls, n	79.42 ± 19.22
Collisions between all objects, n	123.14 ± 30.53
Collisions of targets with other objects, n	96.89 ± 24.78
Occlusions when the target obscures the distractor, n	16.37 ± 6.18
Occlusions between distractors, n	12.45 ± 4.67
Occlusions between targets, n	12.56 ± 4.53
Occlusions when the distractor obscures the target, n	16.42 ± 6.33

Statistical Analysis

The statistical analysis was performed using R (version 4.3.0) and RStudio (version 2024.04.1). Prior to conducting the main analysis, outliers were identified and removed based on the criterion of exceeding 1.5 times the interquartile range. Additionally, logarithmic transformation was applied to variables associated with task parameters to achieve standardization.

To identify the task parameters that influence the accuracy of the 3D MOT task, a Generalized Linear Mixed Model (GLMM) utilizing a Poisson distribution and a log link function was employed to accommodate both fixed and random effects. The accuracy of the MOT task was designated as the dependent variable, while the task parameters were treated as predictors. Participant identification was incorporated as a random effect to account for the repeated measures across the 15 trials completed by each participant. Prior to modeling, a variable selection using L1-penalized estimation was performed to identify the most significant predictors for inclusion in the final model.

To investigate the relationship between the MOT accuracy and the positions of field ice hockey players, a GLMM with a binomial distribution and a log link function was employed. The player position (forward or defenseman) was designated as the dependent variable, while MOT accuracy and selected task parameters served as predictors.

Results

The accuracy of the MOT task was modeled using the GLMM, incorporating participants' ID as a random effect. Preliminary variable selection through L1-penalized estimation indicated that only the motion speed and the number of occlusions, when the distractor obscures the target, emerged as significant predictors based on the coefficients estimation. The GLMM analysis confirmed that both the motion speed and the number of occlusions are significant predictors of MOT accuracy ($p < .001$ and $p = .009$, respectively), that are negatively associated with the tracking performance, with a Marginal R^2 of .18 and a Conditional R^2 of .27.

Furthermore, an examination of the relationship between the player position and the MOT accuracy, while controlling for task parameters, revealed no significant effects (all $p > .05$). This suggests that hockey forwards and defensemen aged 13–15 do not exhibit differences in their 3D MOT accuracy.

Discussion

The aim of the study was to investigate the relationship between the accuracy of a 3D MOT task and the task parameters, as well as the playing positions of field ice hockey players aged 13 to 15 years. Among the task parameters considered in the study (the motion speed of objects, the number of collisions among objects and between objects and walls, the number of occlusions), motion speed and the number of occlusions when the distractor obscures the target were found to be significantly negatively correlated with tracking accuracy.

Even in early experiments, it was demonstrated that at sufficiently low movement speeds, it is possible to track up to eight targets, whereas at very high speeds, only one target can be tracked (Alvarez & Franconeri, 2007). A possible explanation for this phenomenon, as posited by the spatial interference theory, suggests that the redistribution of attention towards targets is accompanied by inhibition of information in surrounding areas . That is why the effect of speed on tracking accuracy is mediated by a change in the distance between objects, which tend to converge more frequently at higher speeds (Franconeri et al., 2010). Conversely, another study indicated that tracking accuracy diminished with increasing speed, even when the distance between moving objects remained constant (Tombu & Seiffert, 2011). The notion that the spatial interference theory may not be universally applicable is further supported by Bouma's law, which states that the degree of proximity of objects required for grouping (where interfered zones overlap) is approximately half the eccentricity of the object (Nador & Reeves, 2023). When this threshold is exceeded, the degree of convergence no longer influences tracking accuracy (Holcombe & Chen, 2013; Holcombe, 2023). Consequently, the findings of the current study suggest that when performing tracking in 3D space, an increase in speed significantly reduces task accuracy. Furthermore, under equivalent speed conditions, accuracy decreases as the number of occlusions (when distractors overlap with targets) increases, which is a well-known effect of MOT (Kamkar et al., 2020). Thus, the spatial proximity of objects appears to at least partially exert an independent effect on tracking performance.

The absence of a significant relationship between object collisions and tracking accuracy observed in the current study partially contradicts prior research, which indicated a diminished ability to detect changes in objects during time intervals close to a collision with a frame (Vater et al., 2017). However, it is important to note that findings from the previous research were derived from a dual-task paradigm and do not directly imply that boundary collisions adversely affect tracking accuracy. Thus, further research is needed to explore this issue. Additionally, a more nuanced examination of the problem of collisions among objects is necessary, as prior studies have treated such collisions as a form of object crowding. This perspective may be somewhat misleading, considering that object crowding is predominantly overcome through foveal processing, whereas abrupt changes in direction are primarily registered by peripheral vision, potentially triggering a saccade toward the new direction (Ibid.).

Furthermore, the results obtained should be interpreted with consideration of the study's limitations. For instance, the types of collisions between objects — whether they occurred between targets, between distractors, or between targets and distractors — and their duration were not addressed. Additionally, this study did not examine task characteristics such as the crowding and distribution of targets across the visual hemifields, which are known to exert a significant influence on MOT (Vater et al., 2017; Iordanescu et al., 2009). It is also particularly pertinent to explore task parameters in relation to the spatial dimensions involved (e.g., differentiating between collisions with the front wall of a cube and those with its side walls). Future studies utilizing eye tracking methodologies that take these

limitations into account will be instrumental in elucidating the factors that impact the accuracy of tracking. The results may have also been influenced by the brief duration of the task, which did not fully allow for the minimization of the learning effect.

The results of the present study also indicated no significant relationships between the MOT performance and the athletes' roles. One potential explanation for this outcome is that the employed methods may represent a limited aspect of the cognitive demands inherent in the complex activity of ice hockey. Although attention is recognized as critical for effective performance across various contexts, the development of the ability to simultaneously track multiple moving objects may not be adequately captured by non-specific paradigms. Consequently, the results obtained may lend support to the perspective that domain-general cognitive functions are inseparably linked with professional knowledge and experience, and should be evaluated using sport-specific paradigms (Mann et al., 2007).

Furthermore, in modern hockey, the role of defensemen is not limited exclusively to defensive actions. A qualified defender takes an active part in offensive actions while forwards perform defensive functions (Johnston & Walter, 2018). It is possible that the distinctions in training and competitive experiences at this developmental stage are insufficient to delineate differences between players' roles, particularly given that participation in team sports inherently influences attention (Rahimi et al., 2022). In this context, the absence of differences between hockey players of different positions may reflect a generalized effect of the training and selection frameworks implemented within a team. Furthermore, it can be posited that specialization in hockey occurs without consideration of perceptual-cognitive abilities. Existing research highlights disparities in physiological profiles and physical fitness among goalkeepers, defensemen, and forwards (Bournival et al., 2023; Daigle et al., 2022), which may represent a more critical factor in achieving athletic performance than the MOT ability. Future investigations should focus on examining the differences among players in elite and semi-elite adult athletes, as long-term specialization may exert a more pronounced influence on cognitive functioning, particularly with respect to the MOT accuracy.

Conclusion

The motion speed and the frequency of occlusions caused by distractors obscuring the target were found to negatively impact the accuracy of the 3D MOT task among ice hockey players aged 13–15 years. This finding underscores the importance of incorporating task parameters in the applied testing of athletes. Furthermore, a more nuanced examination of task parameters, particularly the spatial positioning of objects in relation to the athlete's gaze, is warranted in future research. Additionally, no significant relationship was observed between the MOT performance and the playing positions of adolescent hockey players when controlling for task parameters. This suggests a need for testing athletes using domain-specific tasks, as well as the necessity for future comparisons involving adult athletes in various playing positions.

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