Psychology of Sport & Exercise 76 (2025) 102770

Contents lists available at ScienceDirect

Psychology of Sport & Exercise

journal homepage: www.elsevier.com/locate/psychsport

No transfer of 3D-Multiple Object Tracking training on game performance in soccer: A follow-up study

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ARTICLE INFO

Keywords:
NeuroTracker
Attention
Cognitive performance
Cognitive training
Elite athletes
Sport

ABSTRACT

The impact of domain-general cognitive 'brain' training on improving sports performance is highly debated. This study sought to follow-up on research that showcased the benefits of perceptual-cognitive 3D-Multiple Object Tracking (3D-MOT) training in enhancing the on-field performance of soccer players. Additionally, it explored the correlation between athletes' cognitive performance and early career success.

Sixty-two males from a professional soccer academy were randomly divided into a dual-task 3D-MOT training group ($n = 30$) and a control group ($n = 32$). Participants underwent a 3D-MOT test, a cognitive test of attention, and small-sided games at pre- and post-training. Pre-post-test performances were compared using ANCOVAs. A Chi-squared test evaluated the association between the training regimen and early career success. A Spearman test assessed the correlation between performance on the 3D-MOT, attention test, and early career success.

The dual-task 3D-MOT trained group significantly improved its performance on 3D-MOT compared to the control group ($p < 0.001$). However, no significant pre-post-test differences were observed between the groups in the near-transfer cognitive test and on-field performance ($ps > 0.05$). There were no associations between the athletes' early career success and the training regimen, and no associations between cognitive test performances and early career success ($ps > 0.05$).

This follow-up study failed to replicate previous findings with dual-task 3D-MOT training unable to produce near or far transfer on soccer performance. In addition, cognitive performance was not related to early career success in this study. The value of cognitive screening and training in sport is discussed.

1. Introduction

In high performance sports, improving performance of athletes represents a fundamental goal, and in this objective, the perceptual-cognitive domain has been thoroughly investigated (e.g., Broadbent, Causer, Williams, & Ford, 2015; Lebeau et al., 2016; Richlan, Weiß, Kastner, & Braid, 2023; Zhao, Gu, Zhao, & Mao, 2022). Following evidence showing a positive association between sport expertise and performance on domain-general cognitive tests (Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012; Voss, Kramer, Basak, Prakash, & Roberts, 2010), cognitive training has become widespread in the sports domain. The effectiveness of cognitive training in sports is based on the rationale that it teaches athletes to actively optimize their thoughts and cognitive processes, and that cognitive processes engaged during cognitive training and sports overlap (for more details, see: Mayer, Hermann, & Beavan, 2023). One type of highly advertised form of domain-general cognitive training is referred to as 'brain training'. Its emergence has surged in response to early evidence linking gaming expertise and brain development (Green & Bavelier, 2003), and later, video games training and improvement in inhibition, attention, or working memory (Bediou, Bavelier, & Green, 2021; Chaarani et al., 2022). In the sporting domain, the use of brain training to enhance performance has been subject of debate in recent years (Fransen, 2024; Gobet & Sala, 2022; Harris, Wilson, & Vine, 2018; Renshaw et al., 2018; Vater, Gray, & Holcombe, 2021).

One of the most prominent brain training tools found in the sporting environment is the NeuroTracker™, whose primary task is based on the 3 Dimensional-Multiple Object Tracking (3D-MOT) paradigm (Faubert & Sidebottom, 2012). This task relies on the widely known MOT paradigm developed by Pylyshyn and Storm (for a review, see Meyerhoff,

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https://doi.org/10.1016/j.psychsport.2024.102770
Received 20 May 2024; Received in revised form 14 October 2024; Accepted 16 October 2024
Available online 18 October 2024
1469-0292/

Papenmeier, & Huff, 2017; Pylyshyn & Storm, 1988). The test was developed to simulate the processing of dynamic visual scenes such as those typically found in real life and, more specifically, in team sports (e.g., tracking movements of teammates, opponents, objects, etc.). While the underlying mechanisms are still the subject of investigation, 3D-MOT has been suggested to solicit specific cognitive functions that are believed to be important for sport performance, including attention, processing speed and working memory (Faubert & Sidebottom, 2012; Parsons et al., 2016).

Early evidence has reported that 3D-MOT scores are sensitive to athletes' expertise, showing that visual tracking speed could distinguish elite from sub-elite, and from novice (Faubert, 2013). These results have been replicated in other 3D-MOT or MOT studies (Liu, Zhang, Chen, Zhang, & Li, 2024). These have also found that it could distinguish between athletes of open- and closed-skill sports, as well as sex (Jin, Ji, Wang, & Zhu, 2023; Jin, Zhao, & Zhu, 2023; Legault & Faubert, 2024; Legault, Sutterlin-Guindon, & Faubert, 2022; Wierzbicki, Rupaszewski, & Styrkowiec, 2023; Zhang, Lu, Wang, Zhou, & Xu, 2021). Furthermore, other studies have reported a positive association between real-life performance and user performance on the 3D-MOT task (Gou & Li, 2023; Harenberg et al., 2016; Jarvis, Hoggan, & Temby, 2022; Jin et al., 2020; Mangine et al., 2014; Phillips & Andre, 2023; Tremblay, Tétreau, Corbin-Berrigan, & Descarreaux, 2022), with an exception in ice hockey (Tétreault, Fortin-Guichard, McArthur, Vigneault, & Grondin, 2023). This draws a parallel with other studies demonstrating a relationship between superior on-field success and higher scores in cognitive tasks assessing, for example, executive functions (Cona et al., 2015; Trecroci et al., 2021; Vestberg et al., 2012, 2017). All this evidence has naturally led to testing whether 3D-MOT could enhance human performance. In this regards, some studies have reported evidence of near and mid-transfer benefits on cognitive functions (Assed, de Carvalho, Rocca, & Serafim, 2016; Fleddermann, Heppe, & Zentgraf, 2019; Harris, Wilson, Crowe, & Vine, 2020; Harris, Wilson, Smith, Meder, & Vine, 2020; Parsons et al., 2016; Tullo, Guy, Faubert, & Bertone, 2018; Vartanian, Coady, & Blackler, 2017, 2021), as well as evidence of far transfer benefits on real-life performance in older adults and athletes (Burgos-Morelos et al., 2023; Legault & Faubert, 2012; Michaels, Chaumillon, Mejia-Romero, Bernardin, & Faubert, 2023; Romeas, Guldner, & Faubert, 2016; Snowden et al., 2020). However, other studies in baseball (Furukado et al., 2024), soccer (Harenberg et al., 2021; Phillips, Dusseault, Polly da Costa Valladão, Nelson, & Andre, 2023; Scharfen & Memmert, 2021), volleyball (Fleddermann et al., 2019), and non-athletes (Harris, Wilson, Smith, et al., 2020) have failed to replicate such effects.

In soccer specifically, Harenberg et al. (2021) conducted a study in which they assessed the transfer benefits of a 3D-MOT training in NCAA (div. 3) athletes. The authors used the same training intervention duration as in Romeas et al. (2016), where a significant on-field improvement was found in passing decision-making accuracy (15 %) of male varsity soccer athletes, but not in dribbling or shooting accuracy, following a 3D-MOT training. However, Harenberg et al. (2021) employed a larger sample size following a power analysis and included both females and males ($n = 31$). They also included near and mid-transfer evaluations (e.g., Stroop task, Trail Making Test). Notably, they assessed far transfer on a video-based test that previously demonstrated predictive value for expertise in youth soccer players (Murr, Larkin, & Höner, 2021) and implied simulated action correspondence to soccer decision-making task (e.g., passing or shooting). Instead, Romeas et al. (2016) used a real-setting transfer task with small-sided games. The study revealed no effect of the intervention on cognitive tests or decision-making performance in the video-based test. More recently, Phillips et al. (2023) replicated such studies in 22 NCAA (div. 1) female athletes. They found no significant far transfer effects on statistical measures of game performance (e.g., passing accuracy), but they observed higher improvements in the experimental group compared to the control group after the intervention, in passing accuracy (8.5 % vs 3.5 % respectively) and successful actions (8.2 % vs 4.2 % respectively). Based on these three similar studies, it is still unclear whether 3D-MOT can transfer to game performance, and several critics have been raised against the effectiveness of this training tool (Harris et al., 2018; Vater et al., 2021).

Arguments against the effectiveness of brain training mainly state that there is a lack of evidence and experimental rigor in this domain. For example, in their meta-analysis including studies outside the sporting domain, Sala et al. (2019) demonstrated that when correcting for publication bias and placebo effects, there was no impact of brain trainings on far-transfer measures. More specifically, Vater et al. (2021) reported the following issues with the 3D-MOT task and research around it: small sample size, low statistical power, problems of replication of results, lack of evidence of its impact on visual strategies, and lack of specificity of 3D-MOT. Most prevalent critics towards the task consider that 3D-MOT may resemble some aspects of dynamic sport situations (e.g., soccer) but do not replicate the entire complexity and representativeness of a sport specific situation. In fact, most prevalent theories surrounding expertise development support that the more representative is the training, the more likely it can lead to performance improvement (Hadlow, Panchuk, Mann, Portus, & Abernethy, 2018; Pinder, Davids, Renshaw, & Araújo, 2011; Renshaw et al., 2018). To phrase it differently: "*the more the tasks differ from the context, the more difficult the transfer becomes*" (Mayer et al., 2023).

To improve the sport-specificity of the 3D-MOT task, Romeas, Chaumillon, Labbé, and Faubert (2019) created a multitasking paradigm aiming to simulate the attentional demand and contextual source of information of the sport environment more closely. This dual-task combined tracking multiple objects while perceiving and reacting to specific object trajectories (e.g., birdie in badminton) or movements kinematics (e.g., biological motion perception [BMP] of a moving human). BMP refers to the capacity to recognize kinematic presentations of movements reduced to a few moving dots representing the major joints of the body (Johansson, 1973). This task has been previously shown to accurately predict expertise and has been used in multiple sport settings (Romeas & Faubert, 2015; Smeeton, Hüttermann, & Mark Williams, 2019; Williams, Ward, Knowles, & Smeeton, 2002; Wright, Bishop, Jackson, & Abernethy, 2011). Combining 3D-MOT with BMP was proposed to replicate the broader attentional demand of the sport (e.g., tracking multiple players) that is associated with a more contextual source of information (e.g., perceiving an opponent's intention) during action (Cañal-Bruland & Mann, 2015). Additionally, the task is delivered through virtual reality displays to increase the similarity towards visual and dynamic sources of information within the sports environment (e.g., stereoscopy, field of view). In a previous feasibility study, the dual 3D-MOT-BMP task was shown to induce an important dual-task cost but users were still able to perform above chance level, and more importantly, to improve on the task through training (Romeas et al., 2019).

The current study aimed to follow-up on prior research conducted on soccer athletes (Romeas et al., 2016) in order to clarify the efficacy of 3D-MOT on soccer performance. To improve its design, this study included a larger sample size based on a power analysis, a cognitive test to control for near transfer effect on attentional functions, and two inter-raters for on-field assessment (for a detailed overview of the methodological differences between the two studies, see the Supplementary material). Furthermore, to increase the sport specificity of the task, as well as its challenge, a soccer specific BMP task requiring to anticipate ball trajectories from sport-specific kinematics while keeping track of the other elements of the visual scene (e.g., 3D-MOT) was employed. Lastly, this study aimed to investigate the relationship between 3D-MOT performance, cognitive test performance, and the early career success of players given that 3D-MOT and cognition have been previously linked to success and performance in soccer (e.g., Mangine et al., 2014; Vestberg et al., 2012). Therefore, near (e.g., cognitive test) and far (e.g., on-field performance) transfer benefits of a dual

3D-MOT-BMP task training on soccer players was assessed, as well as its link to early career success (e.g., competition level). It was hypothesized that both near and far transfer would be achieved following training and if so, that the 3D-MOT group would yield greater early career success. Furthermore, it was hypothesized that the 3D-MOT scores, cognitive test performance, and athletes' early career success would be positively correlated.

2. Methods

2.1. Participants

Sixty-two U13 (n = 22), U14 (n = 10), U16 (n = 16) and U18 (n = 14) highly trained (McKay et al., 2022) male soccer players (Mean age ± SEM: 15.36 ± 0.24 years old) were recruited from a professional soccer club academy. The athletes were randomly assigned into two groups: a control (n = 32) and a 3D-MOT training (n = 30) group. Based on an a-priori statistical power calculation using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), a target sample size of 35 participants per group (70 participants in total) was needed to detect an interaction effect of $\eta^2 = 0.162$ (Romeas et al., 2016) in the main analysis (a 2 [group] x 2 [time] analysis of covariance with age as covariate), given $\alpha = 0.05$ and power (1-β) of 0.95. While the available sample included 82 potentially recruitable athletes, only 62 agreed to be recruited for the entire duration of the study. However, this sample size was still twice as large as found in previous studies (Harenberg et al., 2021; Phillips et al., 2023; Romeas et al., 2016). All participants had an annual medical exam as part of their enrolment in the soccer academy and were considered healthy. Before the start of the tests, a screening evaluation was conducted and athletes reported normal or corrected-to-normal vision on both eyes (6/6 or better) with normal stereoscopic acuity (50 s of arc or better on the Frisby test). The experimental protocol and related ethical issues were evaluated and approved by the Comité d'éthique de la recherche of the Université de Montréal and the École de technologie supérieure (#H20160604). All participants were informed about the study both verbally and in writing. They all gave their verbal and written consent.

2.2. Procedure

Following a presentation of the study's objectives, athletes were divided into two distinct groups and were instructed to not take part in any other research activities training throughout the duration of the testing period. Participants had a similar weekly routine, which was limited to their class schedule, training and soccer practice at the club academy.

During a first evaluation, athletes were screened using visual tests (visual acuity, stereoscopy), and responded to questionnaires about their expertise in soccer (Figure 1). They were then tested individually (e.g., pre-tests) on one 3D-MOT session and one cognitive test session under standardized conditions in a quiet room. The following days, their on-field performance was evaluated during small-sided games (SSG) that were videotaped and analysed later using a Game Performance Assessment Instrument (GPAI). Questionnaires relative to their self-perception of game performance were also filled by the athletes immediately after the SSG. This sequence of tests was repeated under the same conditions (e.g., post-tests) after the intervention period of ten weeks.

The intervention period for the 3D-MOT group consisted in a minimum of 16 single-task 3D-MOT training sessions, once or twice a week, for five weeks (e.g., consolidation phase; max sessions: 22), followed by a minimum of 10 dual 3D-MOT-BMP task training sessions, once to three times a week, for five weeks (max sessions: 34). The control group did not follow any 3D-MOT or cognitive training.

2.3. Apparatus

3D-MOT. The 3D-MOT task was a custom-made application developed in Unity (Unity Technologies, USA) for research applications and based on the methodology of previous studies (see Romeas et al., 2016, 2019). During the task, four of eight projected spheres had to be tracked within a 3D virtual volumetric cube space. In the first trial, the spheres moved at a starting speed of 68 cm/s. Then the speed varied between trials according to a 1-up 1-down staircase procedure (Levitt, 1971). The spheres followed a linear trajectory in the 3D virtual space. Deviation occurred only when the balls collided against each other or the walls (Figure 2). This task was displayed in a head-mounted display (HTC VIVE, HTC Corp., Taïwan) and its controllers were used to manually select the four targets of interest at the end of each trial (Figure 2). Each 3D-MOT session lasted about 6 min and consisted of twenty trials. A visual tracking speed threshold (cm/s) was then estimated by the mean of the speeds at the last four inversions.

BMP. The BMP task was created from motion capture recordings of five professional and one experienced soccer players using the Vicon motion capture system (Vicon Industries Inc, USA). Participants were equipped with 24 markers on the following major part of their body: head (2), torso (1), shoulder (1), biceps (3), forearm (3), hand (3), sacrum (1), thigh (3), shin (3), and foot (4). A reflective soccer ball (Nike, USA) was used to track its trajectory. During the acquisition phase, the six participants were required to perform a series of passes and shots towards a fixed target positioned at various pre-established distances on the horizontal plane. In cases where the movement was executed incorrectly or did not reach the target, the participant had to retry the attempt. A total of 261 valid movements were recorded, including 150 passes and 111 shots. These passes and shots were performed in a way that the angle of orientation between the athlete and the target fell within the range of 0–20°. A total of 10 different angles were recorded, with 1–5 repetitions for each angle per athlete. Post-processing of the acquisition was performed using the Nexus software (Vicon Industries Inc, USA). The point-light display kinematics were then incorporated into a custom made Unity program (Figure 3), and worked in a similar manner to a previous study (Romeas & Faubert, 2015). This biological motion front-facing task consisted of the discrimination of the ball direction (right, center or left) of a point-light soccer pass (e.g., for field players) or kick (e.g., for goalkeepers). The goal of this task for a participant was to estimate the direction of the ball based solely on the perception of the body kinematics of the point light soccer player. The participant had to press the right or left button on the HTC VIVE controllers if they estimated that the ball was passed or kicked to their right or left, respectively (for a video example, see: https://osf.io/mfjxs/). The participant was instructed to respond as quickly and accurately as possible in this task.

3D-MOT-BMP. The BMP task was combined with the 3D-MOT task to form a dual 3D-MOT-BMP task (Figure 4). As such, during the 2–7 s of each 3D-MOT trial tracking phase (8 s in total), three point-light soccer passes or kicks randomly appeared in the background of the virtual cube, with a randomized inter-stimulus interval of 0.5–1 s. Movements were randomly selected by the program from the motion database. Instructions to users were to anticipate the direction of the passes (e.g., for field players) or kicks (e.g., for goalkeepers) from the point-light soccer players, while simultaneously tracking four of eight projected yellow spheres moving in the 3D virtual volumetric cube space. For the BMP task, users had to press the left or right trigger from the HTC VIVE controllers according to the direction of the ball as soon as possible once the BMP appeared. At the end of the 3D-MOT tracking phase, they used the same controllers to identify the target balls. Instructions were to complete both BMP and 3D-MOT tasks at the same time, as accurately as possible and without prioritizing one over the other. Recorded variables were the visual tracking speed threshold (cm/s) from the 3D-MOT task, and measures of accuracy and reaction times from the BMP task. The results of the BMP task are out of the scope of this study.

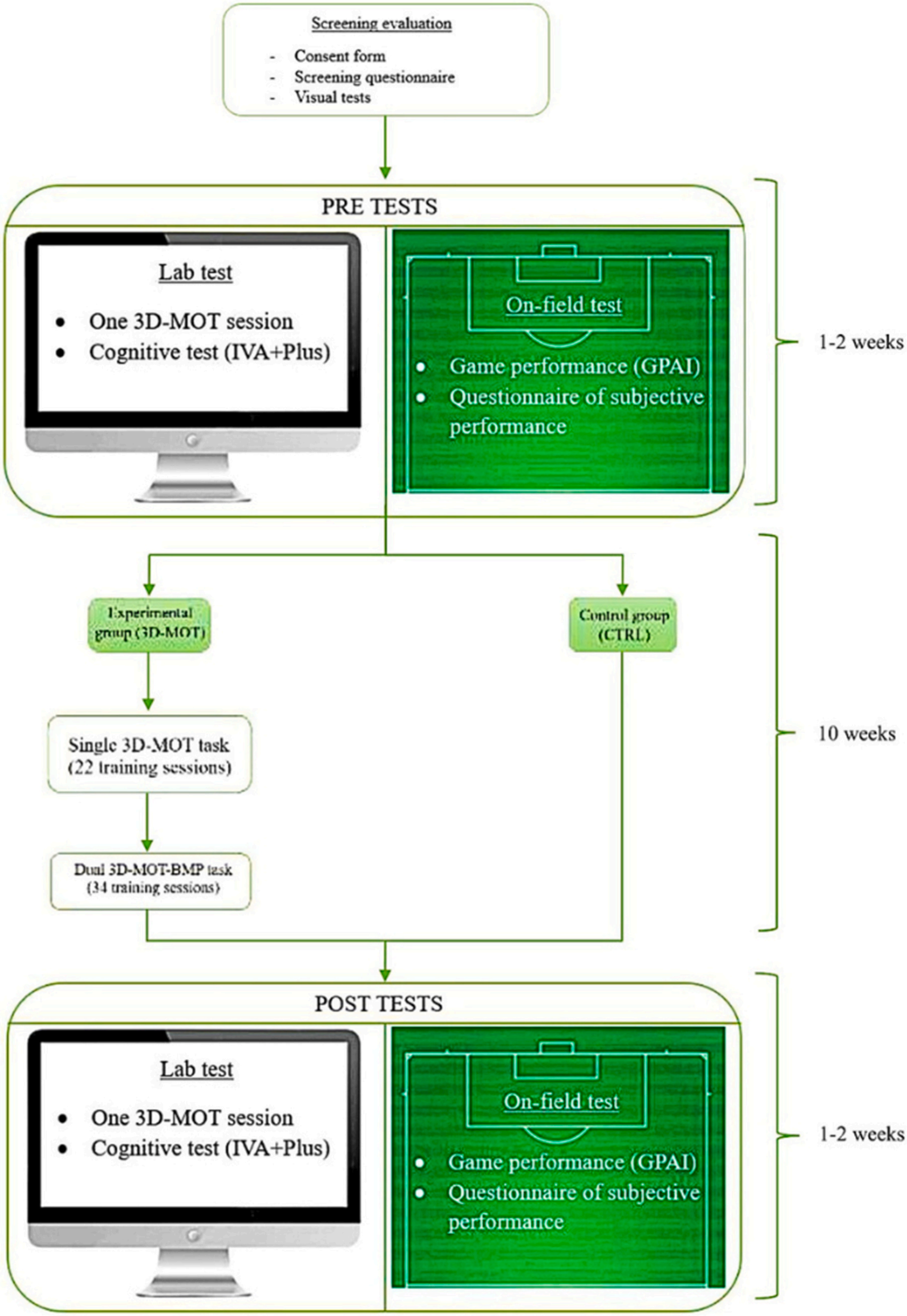

Figure 1. Experimental design of the study.

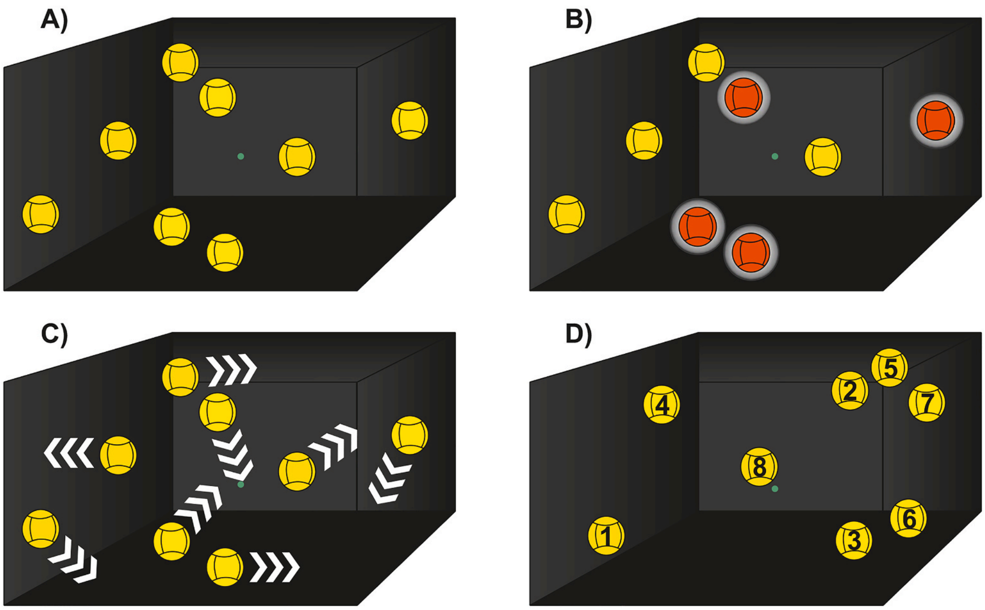

Figure 2. Illustration of one trial during the 3D-MOT task. Presentation of randomly positioned spheres in a virtual volumetric space (A); The four spheres to be tracked during the trial are quickly highlighted in red (B); Removal of identification and movement of all spheres with dynamic interactions (C); Response selection by identifying the spheres (D)

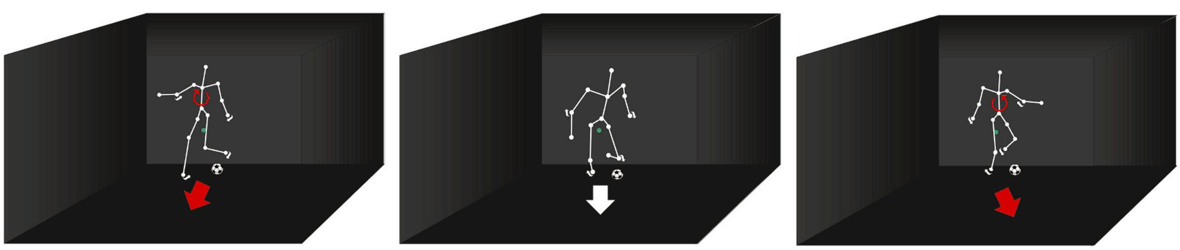

Figure 3. Illustration of the biological motion perception task. A point-light soccer kicker passing or kicking to the left (A), center (B), or right (C) side of the observer.

SSG. The SSG were used to evaluate the players on-field performance before and after the training period. Under the recommendation of the coaches of each group, SSG consisted of standard 5 x 5 or 6 x 6 soccer matches on a 30 m × 50 m indoor turf soccer field to avoid any weather influence. In each age category, players were divided into five opposing teams. The U13 and U14 teams participated in six sets of 5 min SSG, accumulating a total of 30 min of gameplay. The U16 and U18 teams played four SSG, each lasting 7 min, resulting in a combined playtime of 28 min. Players had a 1 min rest between each SSG. The duration of play remained consistent in both the pre- and post-sessions. As in a real game situation, coaches were on the side of the pitch to give their instructions. SSG were recorded using four video cameras (Sony, HDR-CX260VW). Cameras were positioned on cranes positioned in the corners of the field, approximately 10 m above the field of play to cover the entire playing area. Players were identified by jerseys and numbers. The video recordings were analysed using Dartfish Connect v6 (Dartfish, Switzerland).

GPAI. On-field performance during SSG was coded using the GPAI (Oslin, Mitchell, & Griffin, 1998). The assessment was carried out by two experienced soccer coaches (Licence B) blinded to the group distribution and trained to use the instrument for coding. They reviewed the players performance independently. Inter-rater agreement between coders A and B was found to be almost perfect (Cohen's kappa = 0.92). Regarding the pre-test session, coder B reviewed about half as many players performance as the coder A (21 versus 43 players) due to a lack of time. For the post-test session and for the same reason, coder B reviewed only 70 % of the players performance compared to coder A (29 out of the 41 players). The evaluations from coder A were therefore retained for the analysis. Two aspects of on-the-ball performance were evaluated: decision and execution. For the decision making, if the player in possession of the ball selects or attempts a technique appropriate to the situation (e.g., pass, shot, dribble/attack the goal, etc.), then 1 point is awarded for this situation. If the player in possession of the ball selects or attempts a technique inappropriate to the situation, then 0 points are awarded for this situation. For the skill execution, if the player executes a technique resulting in an appropriate outcome (e.g., a pass reaches a teammate, a dribble frees the player from marking, a shot on goal is on target, etc.), then 1 point is awarded for this situation. If the player executes a technique resulting in an inappropriate outcome, then 0 points are awarded for this situation. Once the amounts of appropriate and inappropriate actions were summed for decision making and skill execution, an individual component index was computed for each category. These indexes were established for each participant by dividing the number of points awarded by the total number available. They were then

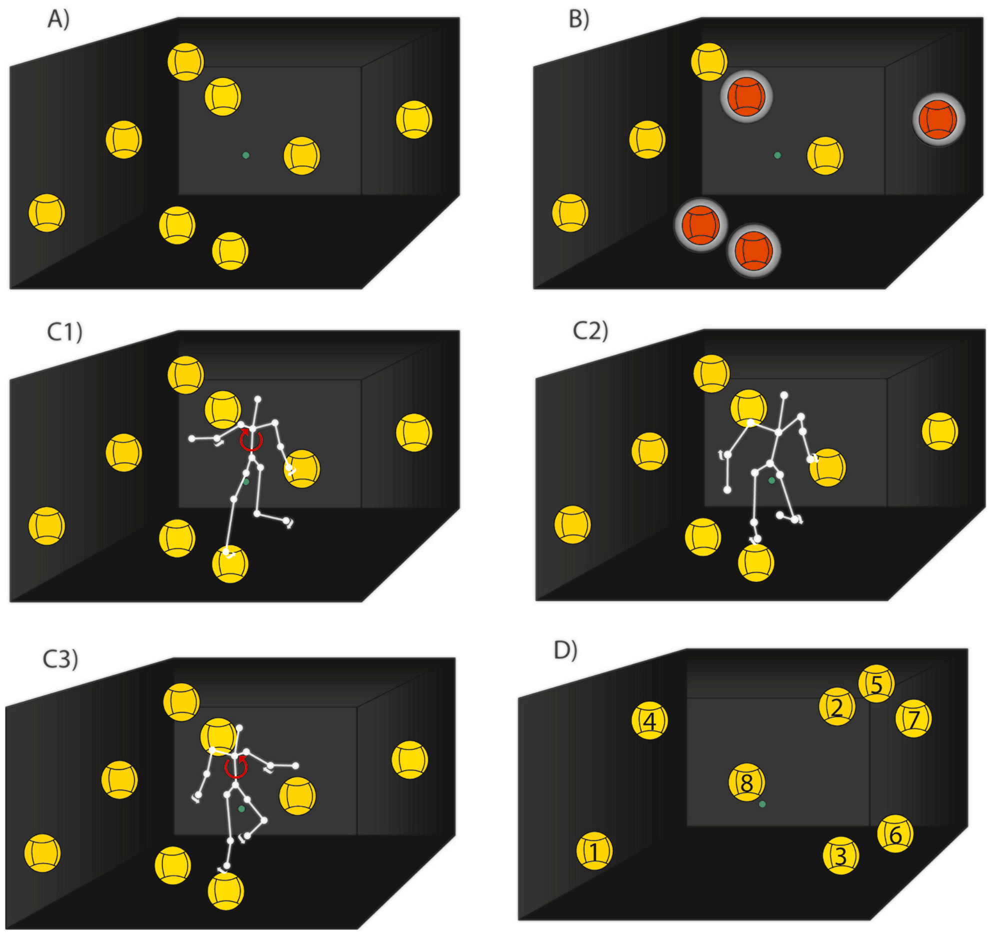

Figure 4. Illustration of the dual 3D-MOT-BMP task in which 4 of the 8 balls must be tracked (B), as well as the trajectory of a ball kicked/passed by a point-light soccer kicker either to the left (C1), center (C2), or right (C3) of the observer.

multiplied by 100 to be transformed into a percentage score for analysis. The Decision-Making Index (DMI) and the Skill Execution Index (SEI) were obtained. Then, the Game Performance (GP) index was calculated by averaging the DMI and SEI scores.

Performance questionnaires. Self-reported performance of players was collected on a Nexus 7 tablet (Samsung, Suwon, South Korea) after pre- and post-SSG using and visual analog scales coded from 0 to 100. Questions related to their SSG overall and cognitive (e.g., explained as focus, reaction speed, etc.) performances were used to assess potential self-perceived improvements. Questions related to their mental and physical states during SSG were used as control measures to ensure that these performance factors were perceived as similar during pre- and post-tests (Supplementary material).

Cognitive test. The Integrated Visual and Auditory (IVA + Plus) test (BrainTrain, Richmond, USA) is a continuous performance task that was used to assess sustained attention (Arble, Kuentzel, & Barnett, 2014; Sandford & Turner, 2004). The test lasted approximately 13 min and involved responding or inhibiting a response for a total of 500 trials, each one lasting 1.5 s, thus requiring constant sustained attention. The task required the participant to click the mouse only when he saw or heard a "1" (target) and not to click when he saw or heard a "2" (distractor). The quotient scores obtained were the Sustained Visual Attention Quotient (SVAQ) and the Sustained Auditory Attention Quotient (SAAQ) which cumulated and weighted the response control quotient and attention quotient for the visual and auditory items, respectively.

Early career success. The career progression of athletes included in this study was tracked, and the first two years following their exit from the academy were taken into account for the analysis (e.g., five years after data collection, to account for the younger group). The early career success of two athletes could not be accounted for because they had not spent two full years outside the academy at the time of the analysis. The

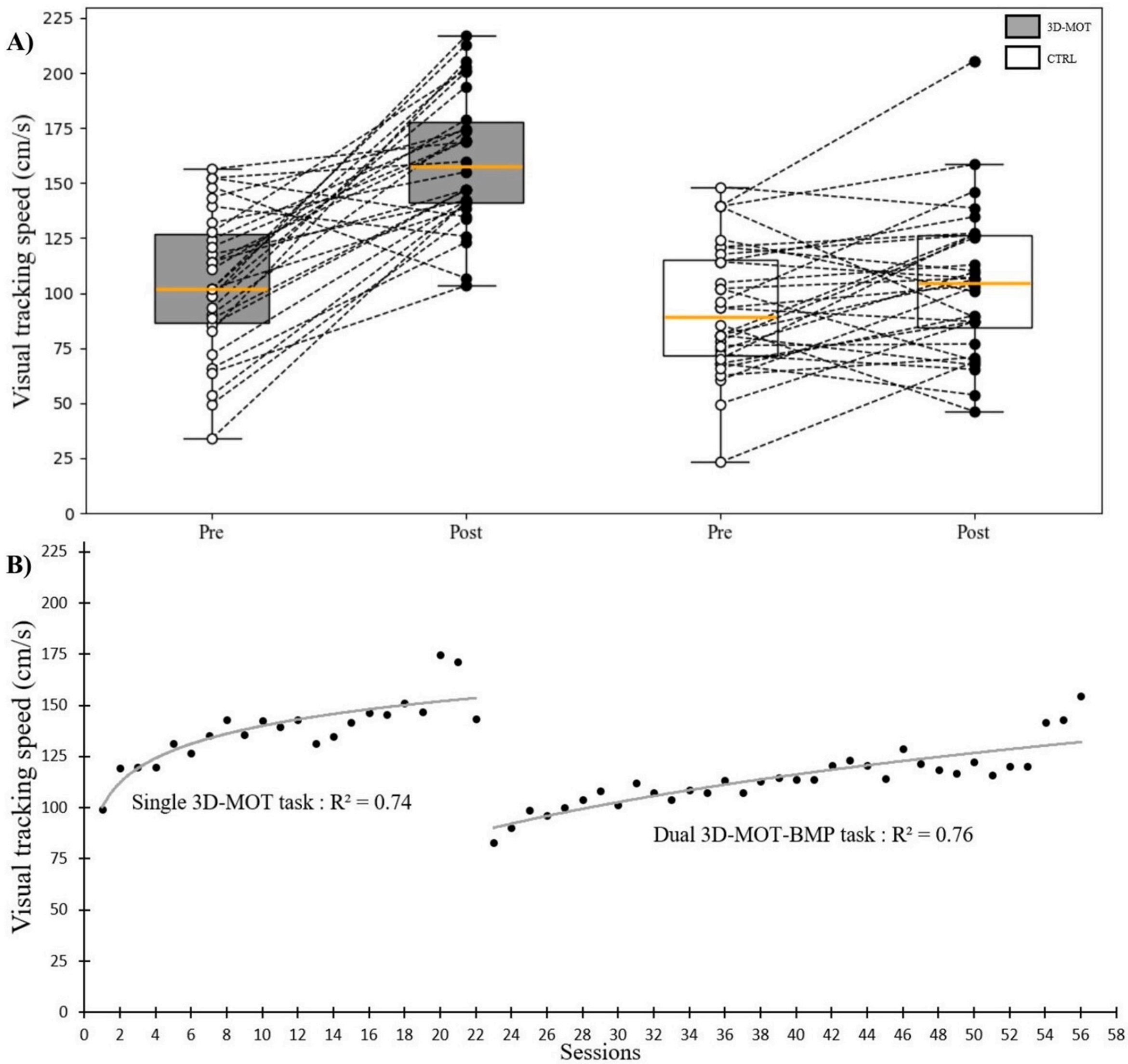

Figure 5. Visual tracking speed scores in a 3D-MOT and a control group at pre- and post-tests (A) and during training for the 3D-MOT group (B).

competition level achieved each year after leaving the academy was assessed on a rank scale ranging from 0 to 6. A score equal to 0 indicated that the player had stopped playing football after the academy. Other levels were ranging from 1 (AA), 2 (AAA), 3 (provincial league level, semi-pro, NCAA), 4 (professional clubs at the national level, USL, MLS 2), 5 (MLS or European div. 1 and 2 clubs) to 6 (International level).

2.4. Analysis

Data inspection. Each variable underwent a screening to detect outliers, and values that were more than three standard deviations above or below the mean were excluded from the analyses. Three players from the 3D-MOT group and 19 from the control group did not complete all the on-field tests at either pre- or post-tests for various reasons (e.g., injuries, absence, etc.), leaving a total of 39 athletes for the on-field test analysis ($N_{3D\text{-}MOT} = 27$; $N_{Control} = 13$). A summary table of missing data and outliers is reported in Supplementary material. A Shapiro-Wilk test was performed to confirm the normal distribution of the variables and residuals. A Levene test was then performed to assess the homogeneity of variances between groups. For the analysis, repeated measures ANOVA or ANCOVA were mainly used, and Bonferroni corrections were applied to correct for multiple comparisons. Eta-squared (η^2) was used to report effect sizes and to characterize the magnitude of the associated effect with respect to the null hypothesis. A threshold of <0.01 described a weak effect, <0.06 a moderate effect and <0.14 a large effect (Cohen, 1988). All statistical analyses were conducted on the IBM SPSS version 29.0.1.0 software and R 4.4.0. For all analyses, the alpha threshold was set to $p < 0.05$.

Manipulation check. To first investigate whether the 3D-MOT group improved more compared to the control group on the 3D-MOT task following training (e.g., manipulation check), a two-way repeated measures analysis of covariance (ANCOVA) was used on the 3D-MOT visual tracking speed scores with the within-subject factor time (pre, post) and the between-subject factor group (3D-MOT, control), including the age as a covariate. Paired Student t-tests were used to compare pre- and post-tests performance in each group. To control for the 3D-MOT improvement in the trained group between the present study and that of Romeas et al. (2016), an ANOVA analysis was conducted on the 3D-MOT scores with the within-subject factor time (pre, post) and the between-subject factor group (2016 study, present study).

Transfer. To assess the transfer effect of 3D-MOT on cognitive performance, a non-parametric Quade test was first performed on the post-pretest difference of each quotient score's variable of the IVA + Plus (SVAQ, SAAQ) with the between-subject factor group (3D-MOT, control) and the covariate age, as the distribution of the variables was not normal. Since the results did not differ from the parametric test, the results of the three-way repeated measures ANCOVA with the within-subject factors quotient scores (SVAQ, SAAQ), time (pre, post), and the between subject factor group (3D-MOT, control) including the age as a covariate, were reported in the manuscript. The same analyses was conducted with the between-subject factor group including three levels (3D-MOT respondents [n = 15], 3D-MOT non-respondents [n = 15], control [n = 32) to further explore whether "respondents" athletes showing substantial improvement in the 3D-MOT task (e.g., above the median) could demonstrate more notable transfer benefits compared to "non-respondents" (e.g., below the median). In addition, because we suspected that the athletes had reached a plateau on the cognitive test, their pre-test performances were compared against standardized normative values from the general population available with the test (SVAQ: M = 100, SD = 10.17, n = 1700; SAAQ: M = 100, SD = 10.10, n = 1700). Two-sample unpaired t-tests for each quotient score's variable (SVAQ, SAAQ) were performed using the mean and standard deviation of athletes against the norms.

To assess the transfer effect of 3D-MOT on the on-field performance, a two-way repeated measures ANCOVA was performed on the GP index of the GPAI with the within-subject factor time (pre, post) and the between-subject factor group (3D-MOT, control) including the age as covariate. To investigate potential on-field performance differences between decision and execution, a three-way repeated measures ANCOVA with the within-subject factors GPAI indexes (DMI, SEI), time (pre, post), and the between-subject factor group (3D-MOT, control) including the age as covariate, was used. The same analyses were conducted with the between-subject factor group including three levels (3D-MOT respondents [n = 13], 3D-MOT non-respondents [n = 13], control [n = 13]).

Furthermore, a three-way repeated measures ANCOVA was used on the questionnaire scores related to overall and cognitive performance, as well as physical and mental states during SSG with the within-subject factor questionnaire type ([overall, cognitive] or [physical, mental]), time (pre, post), and the between-subject factor group (3D-MOT, control), including age as covariate.

Correlations with early career success. A Chi-square test (χ^2) was employed to assess whether the group factor (3D-MOT, control) was associated with players' early career success. To further explore the link between cognitive performance and early career success, a Spearman correlation was performed between the 3D-MOT scores as well as IVA + Plus quotient scores (SVAQ, SAAQ) obtained at pre-test and the rank of players' early career success.

3. Results

The main results are reported below. All results are fully accessible online in the form of data output (https://osf.io/mfjxs/), however, the authors are not permitted to share the raw data due to restrictions imposed by the ethics committee that reviewed the project.

3.1. Manipulation check

There was a large significant interaction between Time and Group ($F[1,59] = 22.270$, $p < 0.001$, $\eta^2 = 0.274$). Post-hoc comparisons demonstrated a significant improvement between pre- and post-tests in the 3D-MOT group ($t[29] = -7.344$, $p < 0.001$) which exhibited a greater improvement (+56.42 cm/s) than the one observed in the control group (+11.41 cm/s), which was also significant ($t[31] = -2.235$, $p = 0.033$; Figure 5). The 3D-MOT improvement in the trained group of the present study was not significantly different from the improvement observed in the 2016 study ($F[1,37] = 3.409$, $p = 0.073$, $\eta^2 = 0.084$).

3.2. Near transfer assessment

Cognitive test. There was no significant Time by Index by Group interaction ($F[1,56] = 0.000$, $p = 0.983$, $\eta^2 = 0.000$) and no other significant interactions or main effects (Figure 6). However, there was a significant difference between players' scores and the normative mean on the SVAQ ($t[1757] = 8.71$, $p < 0.001$) and the SAAQ ($t[1757] = 12.10$, $p < 0.001$) scores. The athletes scores (SVAQ: M = 111.97, SD = 15.17, n = 59; SAAQ: M = 116.53, SD = 15.31, n = 59) exceeded those of the normative sample (SVAQ: M = 100, SD = 10.17, n = 1700; SAAQ: M = 100, SD = 10.10, n = 1700). When conducting the Time by Index by Group analysis with the group factor including three levels (respondents, non-respondents, control), no results were significant.

3.3. Far transfer assessments

GPAI. There was no statistically significant interaction between the factors Time and Group on the GP index ($F[1,36] = 0.017$, $p = 0.898$, $\eta^2 = 0.000$; Figure 7A). Similarly, there was no statistically significant interaction between the factors Time, GPAI indexes and Group ($F[1,36] = 0.536$, $p = 0.469$, $\eta^2 = 0.015$; Figure 7B and 7C). The interaction of Time by Index by Age was significant ($F[1,36] = 4.557$, $p = 0.040$, $\eta^2 = 0.112$) as well as the interaction between Time and Index ($F[1,36] = 4.906$, $p = 0.033$, $\eta^2 = 0.120$), but the post-hoc analysis did not report any significant differences. When conducting the analysis with the group factor including three levels (respondents, non-respondents, control), no results were significant.

Questionnaires. There were no significant results for the questionnaires related to SSG overall and cognitive performance, as well as questionnaires related to mental and physical states ($ps > 0.05$).

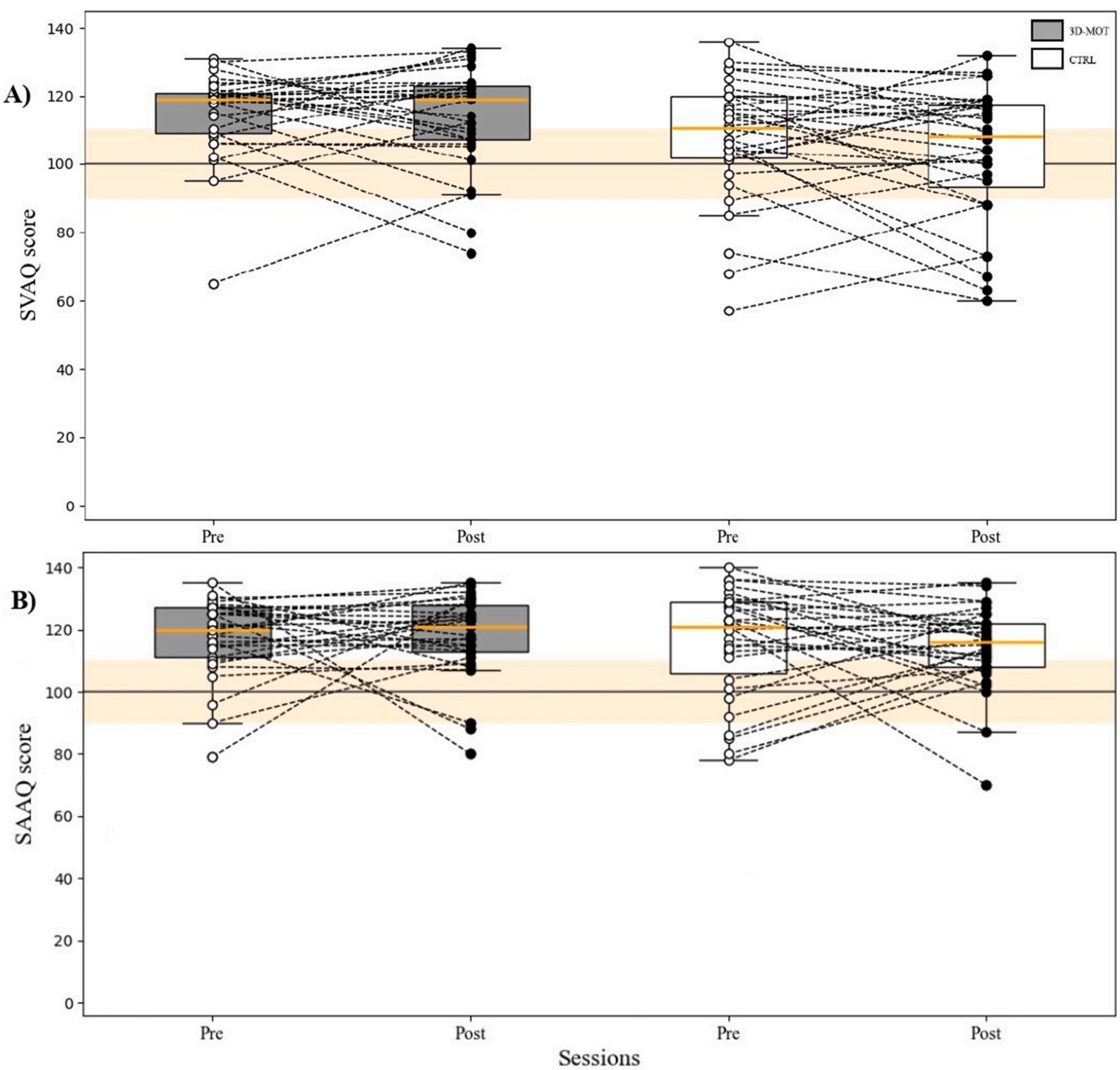

Figure 6. Cognitive performance of soccer players from a 3D-MOT and a control group during pre- and post-tests using the Sustained Visual Attention Quotient score (A) and the Sustained Auditory Attention Quotient score (B) from the IVA + Plus test. The black line represents the normative mean (M = 100), and the yellow ribbon demarcates the standard deviation from the mean (SD = 10).

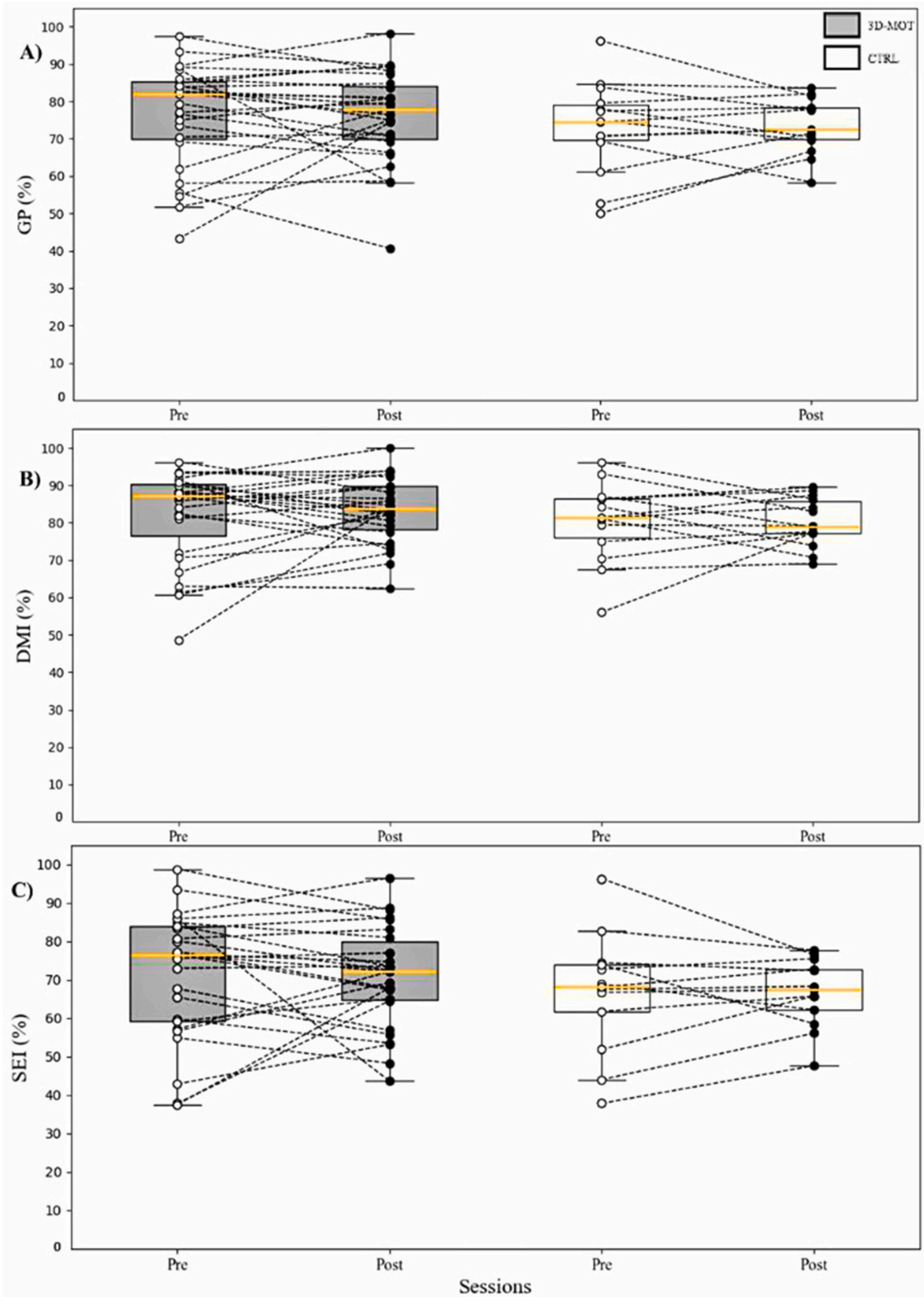

Figure 7. On-field performance of soccer players from a 3D-MOT and a control group during pre- and post-tests using the Game Performance scores (A), the Decision Making Index (B) and the Skills Execution Index (C).

Table 1
Competition level achieved within the first two year after leaving the academy.

	Group					
	3D-MOT		Control		Total	
Competition level rank	n	%	n	%	n	%
N/A	2	6.7	0	0.0	2	3.2
0	5	16.7	3	9.4	8	12.9
2	5	16.7	5	15.6	10	16.1
3	7	23.3	11	34.4	18	29.0
4	9	30.0	9	28.1	18	29.0
5	2	6.7	4	12.5	6	9.7
Total	30	100.0	32	100.0	62	100.0

N/A: Not applicable, two athletes could not be accounted for because they had not spent two full years outside the academy at the time of the analysis.

3.4. *Early career success assessment*

The results demonstrated no significant association between the training regimen and athletes early career success ($\chi^2 = 1.797$, $p = 0.773$; Table 1).

3.5. *Cognitive performance and early career success*

The Spearman correlation matrix revealed no significant associations between the 3D-MOT score, the cognitive test variables, and the early career success (Figure 8). There was a significant positive correlation between the SVAQ and SAAQ scores of the cognitive test ($r = 0.514$, $p < 0.001$).

4. Discussion

This follow-up study sought to assess the near and far transfer effects of a dual-task perceptual-cognitive 3D-MOT training program on soccer players. The findings revealed no meaningful evidence of near transfer effects on cognitive test performance, or far transfer effect on on-field performance. Additionally, no association between the 3D-MOT training regimen and athletes' subsequent early career success could be observed. Lastly, no significant correlation was identified between athletes' attentional performance on the 3D-MOT, an attentional cognitive task, and their early career success.

4.1. *Transfer*

The manipulation check confirmed a significant and substantial improvement in the 3D-MOT trained group compared to the control group. This improvement aligns with findings from prior studies in athletic populations (e.g., Faubert, 2013; Legault et al., 2022; Romeas et al., 2016). Conversely, the marginal improvement observed in the control group between pre- and post-tests could likely be attributed to a familiarization effect.

Despite this task-specific improvement within the 3D-MOT group, the training regimen failed to yield significant near-transfer benefits on a sustained attention task. Scores in the IVA + Plus test indicated no meaningful pre-post changes in the SVAQ (3D-MOT: −1.24; Control: −4.07) or SAAQ (3D-MOT: +0.42; Control: −1.53), contradicting our hypothesis regarding attention enhancement through the 3D-MOT task. Despite recent evidence of video games (e.g., Tetris) that do not have a near transfer effect on mental rotation in healthy subjects (Timm, Huff, Schwan, & Papenmeier, 2024), there is a prevailing consensus that cognitive training produces immediate near-transfer effects (Harris et al., 2023; Melby-Lervåg, Redick, & Hulme, 2016; Sala et al., 2019). More specifically, previous research has shown enhancements in attention following 3D-MOT training, as evidenced by improvements in the same IVA + Plus continuous performance task (Parsons et al., 2016) as well as in visual processing speed and working memory (Fleddermann et al., 2019; Harris, Wilson, Crowe, & Vine, 2020; Harris, Wilson, Smith, et al., 2020; Parsons et al., 2016; Vartanian et al., 2017, 2021). One potential explanation for the lack of near-transfer effects observed in our study relates to the use of an athletic population compared to previous studies that involved young adults, such as Parsons et al. (2016). In fact, it is suggested that athletes yield above-average cognitive performance (Scharfen & Memmert, 2019; Voss et al., 2010), particularly in attention tasks (Vona, de Guise, Leclerc, Deslauriers, & Romeas, 2024), which could therefore limit the room for improvement on cognitive tasks.

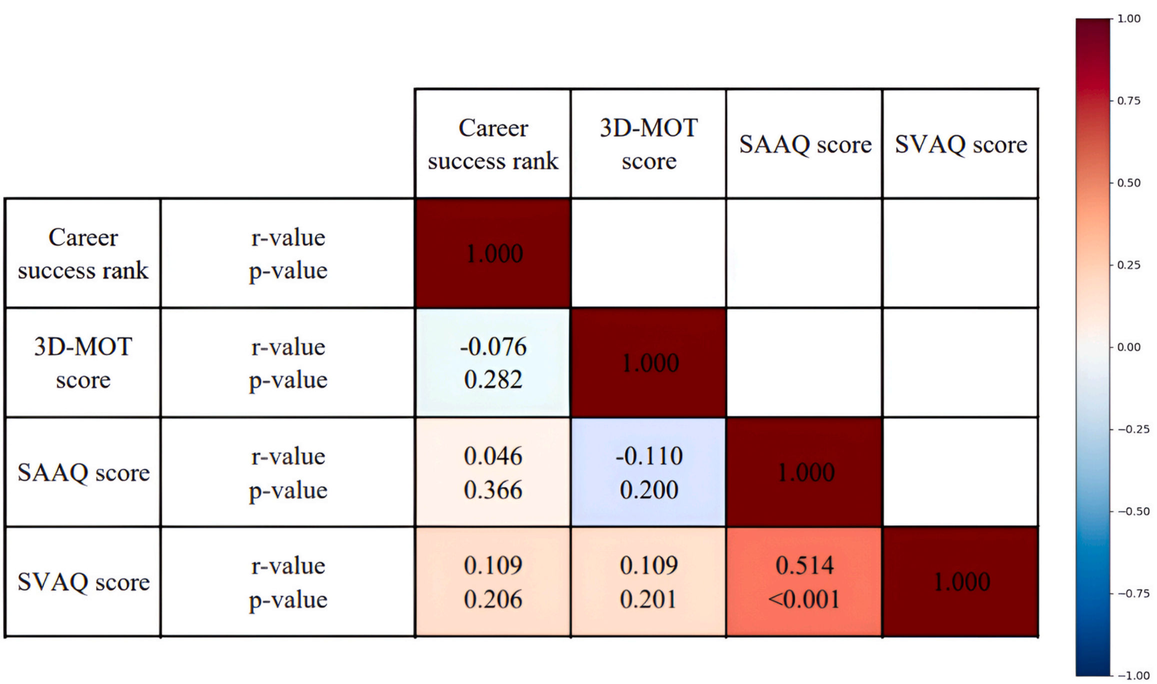

Figure 8. Spearman correlation matrix comparing the association between athlete's early career success and first 3D-MOT, Sustained Visual Attention Quotient (SAAQ), Sustained Auditory Attention Quotient (SVAQ) scores.

Notably, athletes' quotient scores from their first exposure to the test were consistently above average compared to the normative range, indicating limited potential for further enhancement. Moreover, it is also plausible that the IVA + Plus test engages other cognitive functions as the 3D-MOT, and that the latter failed to induce mid-transfer benefits. Correlation analysis between both tasks' initial scores revealed no significant association, suggesting they might tap into distinct cognitive processes. Additionally, the IVA + Plus task encompassed multisensory elements, while the 3D-MOT primarily relied on visual components. Notably, previous research has shown no mid-transfer effects of 3D-MOT on tasks related to executive functions or fundamental visual functions in athletes (Harenberg et al., 2021; Moen, Hrozanova, & Pensgaard, 2018; Scharfen & Memmert, 2021). Given the absence of near-transfer effects, the likelihood of far transfer becomes less likely, unless the 3D-MOT taps into mechanisms other than those evaluated by the cognitive task.

Contrary to prior research findings (Romeas et al., 2016), we observed no far-transfer effects in this study. Instead, the present findings align more closely with the null effects reported in previous soccer and volleyball studies (Fleddermann et al., 2019; Harenberg et al., 2021). Of note, Fleddermann et al. (2019) revealed that player's accuracy levels reached around 97–98 % in the far-transfer task, leaving minimal room for improvement. Similarly, GPAI scores obtained in this study, in particular the DMI, consistently yielded high accuracy scores (around 80–90 %) at both pre- and post-tests. These high scores limit the scope for on-field performance improvement. Conversely, studies that reported noteworthy performance enhancements in 3D-MOT trained groups (e.g., 8–15 %) observed on-field accuracy levels of approximately 60 % probably due to lower expertise (Phillips et al., 2023; Romeas et al., 2016), allowing for greater potential for improvement. Similarly, a recent study showed an improvement in on-field performance of approximately 13 % in a group of young soccer players trained with a MOT test compared to a control group, with on-field performance ranging between 40 % and 60 % (Feria-Madueño, Monterrubio-Fernández, Mateo Cortes, & Carnero-Diaz, 2024). Another difference with the previous study (Romeas et al., 2016) is that the statistical approach used in the current one is more robust. Although the sample size deviate slightly from the expectations of the G-power analysis due to inherent limitations of field studies, it was still three times larger in the experimental group compared to the previous study (27 vs 9 athletes). In the previous study, the control and active control groups were combined to increase the 'control' group size. Additionally, the scoring scale between the two studies was different. In the current study, we chose to focus more on overall 'decision making' with the GPAI rather than individual passes, dribbles, or shots, as our hypothesis was that the intervention should have a comprehensive effect, not isolated on specific actions like passes. Moreover, the GPAI allows distinguishing decision making from execution, which was not the case in the previous study. However, our hypotheses did not suggest that cognitive training in the form of 3D-MOT could improve execution, as cognitive technique such as mental imagery could, for example (Lindsay, Larkin, Kittel, & Spittle, 2023).

Furthermore, it is possible that the transfer task was not discriminative enough. A significant limitation to acknowledge was the lack of objective corresponding metrics between the transfer task and the training regimen. In fact, coding instruments such as the GPAI measured the general game performance irrelevant of the ability to track multiple objects on the field (3D-MOT) or reading body kinematics and anticipating ball trajectories (BMP). However, on-field performance is multifactorial, and the GPAI might be unable to capture subtle changes in such skills. In both the present and prior studies (Romeas et al., 2016), various mechanisms were suggested to explain how 3D-MOT training could enhance performance, such as through overlapping attentional processes engaged in both the 3D-MOT and on-field tasks. More precisely, we suggested in the present study that the association of attentional tracking of moving targets (3D-MOT) with contextual sources of information such as soccer-specific kinematics (BMP) could replicate similar peripheral visual strategies (e.g., foveal spot, gaze anchor, visual pivot) and cognitive demand involved in team sports like soccer (for a review, see Vater, Williams, & Hossner, 2020). However, these specific visual strategies and attentional demand were not directly assessed in situ. Even if an eye tracker cannot necessarily characterize the focus of attention (e.g., covert attention), it could have offered valuable insights into whether similar strategies were used in both the 3D-MOT-BMP task and soccer specific task (e.g., Aksum, Magnaguagno, Bjørndal, & Jordet, 2020), giving more support to its use. For instance, Harris, Wilson, Smith, et al. (2020) demonstrated that following 3D-MOT training, working memory capacity improved, but not the visual strategies on a MOT task. Also, a recent study showed significant differences in gaze strategies between athletes and non-athletes on an MOT task, but no difference in task performance between the two groups (Styrkowiec et al., 2024). So before exploring potential far transfer effects, it is critical that future 3D-MOT studies primarily focus on investigating further the association between the 3D-MOT task and the perceptual-cognitive strategies employed in situ during sports.

Moreover, the self-perceived general and cognitive on-field performance ratings of athletes showed no difference between pre- and post-SSG, indicating that they didn't perceive any advantages from the training regimen. This is another deviation from earlier findings where athletes reported a self-perceived improvement following 3D-MOT training (Romeas et al., 2016). Moreover, the questionnaires used to control for mental and physical states after pre- and post-SSG did not show any difference in this study. This suggests that athletes were equally engaged physically and mentally in both pre- and post-tests, and these factors, although subjectively collected, did not interact with the observed effect.

Lastly, we explored the impact of being a "respondent" (i.e., larger training gains) to 3D-MOT training on the transfer tasks. In high-performance sport, the new standard is to adopt individualized training approaches, considering respondent and non-respondent athletes, acknowledging that a one-size-fits-all strategy may not be suitable to optimize performance at the individual level. More specifically to cognitive training, this concept has been applied to demonstrate that certain individuals respond differently to training and transfer, as some might derive greater benefits from training than others (Jaeggi, Buschkuehl, Jonides, & Shah, 2011). In this study, we found no difference in near or far transfer effects between the 3D-MOT respondents, 3D-MOT non-respondents and controls. This indicates that even individuals who showed the larger 3D-MOT gains (e.g., the respondents) did not demonstrate greater performance outcomes in transfer tasks, contributing to the ongoing debate criticizing attempts to justify individualize training approaches in cognitive training domains (Gobet & Sala, 2022).

In line with the absence of near and far transfer, no association was found between the training regimen and athletes' early career success two years following their exit from the soccer academy. This confirms the lack of short- and long-term benefits associated with the 3D-MOT training in this study. Despite the challenges of conducting on-field transfer studies and the inherent limitations in the present study's design, this follow-up study included a better methodology and a more robust statistical approach, but failed to replicate previous findings (Romeas et al., 2016). Overall, the mixed results in 3D-MOT study outcomes suggest that it is premature to anticipate that 3D-MOT training alone can enhance soccer performance.

4.2. *Cognitive performance and success*

When comparing the athletes' early career success with their initial attentional performance during the study in both the 3D-MOT and the attentional IVA + Plus tasks, we found no significant associations among these three variables, contrary to our initial hypothesis. It is widely acknowledged that cognition plays a pivotal role in athletic performance and that higher sport expertise is associated with better cognitive test performance (Kalén et al., 2021; Logan, Henry, Hillman, & Kramer, 2022; Scharfen & Memmert, 2019; Voss et al., 2010). Our findings from the attentional task also suggest that athletes perform above the average normative range. Another belief, albeit less substantiated, suggests that the cognitive demands of sports require superior fundamental cognitive abilities (e.g., attention, planning, and decision-making), which may result in better on-field performance (Vestberg et al., 2012). In fact, relationships between superior on-field success and higher scores in laboratory-based tasks have been documented (Cona et al., 2015; Trecroci et al., 2021; Vestberg et al., 2012, 2017). Likewise, previous evidence has linked 3D-MOT performance to on-field success in basketball (Gou & Li, 2023; Jin et al., 2020; Mangine et al., 2014). These studies often used game statistics collected throughout a season as performance measures and to test whether 3D-MOT can be predictive of game success. Conversely, our study compared attention and 3D-MOT test scores with early career success in athletes for the first time, revealing no direct correlation. Although career success relies on multiple factors, these findings align with those obtained by Tétreault et al. (2023), which demonstrated no association between performance in 3D-MOT and draft ranking (e.g., assessed retrospectively) or game-related statistics in ice hockey. Hence, although cognition is crucial and could be one of several contributing factors, by itself, it might not be indicative of superior future performance, especially when assessed solely through any domain-general cognitive tasks or 3D-MOT. Therefore, our results aligns with the idea that it is still premature to rely on such tests for talent identification with the present level of evidence and more research is needed in that area (Furley, Schütz, & Wood, 2023; Vona et al., 2024). Meanwhile, it seems more relevant to focus on more representative domain-specific tests targeting functions similar to those engaged in sports (Kalén et al., 2021), although these also require validation (Dong, Berryman, & Romeas, 2023).

4.3. Implications of cognitive training in sport

A statement increasingly common in the literature argues that far transfer might not actually exist (Fransen, 2024; Gobet & Sala, 2022; Harris et al., 2023; Sala & Gobet, 2017). In fact, experts propose that while there is strong evidence supporting that brain plasticity occurs through training, the training benefits primarily remain domain-specific (Sala et al., 2019). In this context, representativeness holds significance. Quite logically, skill acquisition interventions that are more representative of real-world scenarios are suggested to yield greater learning outcomes (Hadlow et al., 2018; Pinder et al., 2011; Renshaw et al., 2018), even if their accuracy in applied settings still requires further clarification (Choo, Novak, Impellizzeri, Porter, & Fransen, 2024). Based on this approach, several studies (including the present one) endeavored to enhance the representativeness of the 3D-MOT task, employing methods such as 360° virtual reality environments and multiple players tracking on virtual soccer pitch. However, these attempts failed to demonstrate far transfer benefits or struggled to establish clear associations between multiple players tracking and soccer expertise (Ehmann et al., 2021, 2022; Vu, Sorel, Limballe, Bideau, & Kulpa, 2022). While these studies improved the physical 3D-MOT fidelity to soccer, they fell short in replicating a comprehensive representation of soccer real-world tasks, lacking functional elements such as stimulus correspondence (e.g., natural movement kinematics), or action correspondence (e.g., perception-action coupling). Similar results could also be observed with domain-specific tests which were lacking representativeness towards the task being measured (Dong et al., 2023). Even if the purpose of cognitive training has never been to replace specific training but rather to complement it, an increasing body of evidence indicates that to date, representative domain-specific training should always be prioritized over generic training methods for direct sport performance enhancement, particularly in domains such as skill training (Kalén et al., 2021; Zhao et al., 2022), until more evidence supports the use of cognitive training. From a technological standpoint and as a complement to coach's learning designs, tools such as virtual reality hold promise for developing unique training paradigms and simulating constraints that accurately represent real-world scenarios (Faure, Limballe, Bideau, & Kulpa, 2020; Richlan et al., 2023), provided that they are scientifically validated (Brock, Vine, Ross, Trevarthen, & Harris, 2023; Drew et al., 2020; Harris, Buckingham, Wilson, & Vine, 2019).

To conclude, the present and other accumulating evidence failed to produce any far transfer on performance which questioned about the practical significance of domain-general cognitive testing and training in sport. Perhaps these tools could find value in the daily monitoring of athletes' cognitive demand (Perrey, 2022), injury prevention and rehabilitation (Chermann, Romeas, Marty, & Faubert, 2018; Deschamps, Siguère-Lemieux, Fait, & Corbin-Berrigan, 2022; Radafy, Detymowski, Kassasseya, & Chermann, 2023), or for creating more ecological agility tests and warm-ups (Friebe et al., 2024; Hülsdünker et al., 2023). For example, in their randomized controlled trial study, Friebe et al. (2024) demonstrated that agility training requiring response to visual stimuli or dual-task agility training combined with MOT resulted in greater soccer-specific test performance compared to simple change of direction training. In addition, several studies have suggested that cognitive training may hold potential to enhance sports performance by improving cognitive endurance (Roelands & Bogataj, 2024). In fact, results from 'brain endurance training' have showed that combining cognitive training before, during or after physical training improves performance greater than physical training alone (Dallaway, Lucas, & Ring, 2021, 2022; Staiano et al., 2022, 2023). This approach allows to increase the overall training load without adding more physical load. Nevertheless, recent contradictory evidence has revealed that such training yields only near transfer benefits (de Lima-Junior, Silva, Ferreira, & de Sousa Fortes, 2023), requiring further evidence in this domain of application as well. In anticipation of more robust evidence, it is recommended that when engaging in cognitive training, practitioners should rather aim at and promote potential gains in near transfer effects at best, without advocating or promoting direct generalized performance benefits. This consideration might extend to the entire field of psychological interventions that aim at enhancing performance, as a recent meta-analysis suggests (Reinebo, Alfonsson, Jansson-Fröjmark, Rozental, & Lundgren, 2023).

4.4. Limitations

This study has several limitations. Firstly, the protocol was not preregistered as recommended for replication studies (Tackett, Brandes, King, & Markon, 2019). Despite efforts to increase sample sizes compared to previous studies, a significant number of athletes were unable to participate in on-field tests due to various reasons outside of our control, resulting in an unequal number between groups. Due to limited access to players, an 'active-control group' was not included, prioritizing sample size in each group over the presence of an additional placebo group. Additionally, the two raters were familiar with the players being evaluated and one rater couldn't complete all evaluations. However, the inter-rater agreement was excellent in the assessed situations. Furthermore, the protocol in this study slightly deviated from Romeas et al (2016). For instance, we employed a different notational scale (e.g., GPAI vs decision making coding instrument) as we aimed to differentiate decision making from execution, considering that our focus was less on execution. Moreover, the 3D-MOT task differed slightly in this study, being more challenging (e.g., dual-tasking) due to the addition of the BMP task, which may have contributed to a lower training quality (e.g., inadequate challenge). However, a comparable number of training exposure hours were completed between both studies. When comparing the 3D-MOT improvement of the trained group between the two studies, although the improvement was slightly higher in the 2016 study, the difference with the present study was not statistically significant ($p > 0.05$). In addition, it must be acknowledged that career success is multifactorial. Therefore, it would have been challenging to directly associate transfer effects in a few hours of 3D-MOT training with career success, even if transfer effects had been observed. Lastly, the transfer measures lacked specificity toward the trained task, possibly hindering the capture of any improvements associated with the training task.

5. Conclusion

The results of this follow-up study contradicted previous findings by showing that the dual-task 3D-MOT training did not produce any near or far transfer effects on the performance of soccer players. Furthermore, attentional abilities assessed in the 3D-MOT test and an attention task showed no association with the athletes' future early career success. These findings contrast with the accumulating evidence of the association between 3D-MOT and performance metrics, as well as the role of cognition in sport. Therefore, the contribution of domain-general screening and training tools like the 3D-MOT on sport performance requires further quality study with larger samples and representative outcome measures.

CRediT authorship contribution statement

Romeas Thomas: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Goujat Maëlle:** Writing – original draft, Formal analysis, Data curation. **Faubert Jocelyn:** Writing – review & editing, Supervision, Software, Resources, Methodology, Investigation, Funding acquisition, Conceptualization. **Labbé David:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of interest

Jocelyn Faubert is a co-founder of CogniSens Athletics Inc. who produces the commercial version of the 3D-MOT (NeuroTracker™) used in this study. In this capacity, he holds shares in the company. The other authors have no potential conflicts of interest to declare.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT 4.0 in order to improve the language quality of some section of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Funding

This work was supported by a Mitacs Acceleration grant (IT06566).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Jocelyn Faubert is a co-founder of CogniSens Athletics Inc. who produces the commercial version of the 3D-MOT (NeuroTracker™) used in this study. In this capacity, he holds shares in the company. The other authors have no potential conflicts of interest to declare.

Acknowledgments

The authors would like to thank Vadim Sutyushev for programming the virtual reality tasks, and Geralt Parent for his help with the motion capture system.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2024.102770.

Data availability

The authors do not have permission to share data.

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