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Gaze Behavior and Cognitive Performance on Tasks of Multiple Object Tracking and Multiple Identity Tracking by Handball Players and Non-Athletes

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Abstract

Multiple object tracking (MOT) and multiple identity tracking (MIT) each measure the ability to track moving objects visually. While prior investigators have mainly compared athletes and non-athletes on MOT, MIT more closely resembles dynamic real-life environments. Here we compared the performance and gaze behavior of handball players with non-athletes on both MOT and MIT. Since previous researchers have shown that MOT and MIT engage different eye movement strategies, we had participants track 3-5 targets among 10 moving objects. In MOT, the objects were identical, while in MIT they differed in shape and color. Although we observed no group differences for tracking accuracy, the eye movements of athletes were more target-oriented than those of non-athletes. We concluded that tasks and stimuli intended by researchers to demonstrate that athletes' show better object tracking than non-athletes should be specific to the athletes' type of sport and should use more perception-action coupled measures. An implication of this conclusion is that the differences in object tracking skills between athletes and non-athletes is highly specific to the skills demanded by the athletes' sport.

Keywords: multiple object tracking, multiple identity tracking, eye tracking, gaze behavior, athletes, non-athletes

Introduction

Multiple object tracking (MOT) and multiple identity tracking (MIT) are two experimental paradigms for studying human ability to track moving objects visually. In a typical MOT task, developed originally by Pylyshyn and Storm (1988), the participant is first presented with a fixed number of randomly arranged identical objects, some of which are briefly marked as targets, while the remaining objects are considered distractors. After target designation, the display is set into motion so that all objects move randomly in independent trajectories and bounce off each other and the display borders. After the tracking period (usually lasting up to a dozen seconds), the motion stops, and the observer's task is to indicate the status (i.e., target or distractor) of either one probed object or of all objects (mark-all; Hulleman, 2005). In the MOT task, because the objects are visually identical, targets can only be distinguished from distractors by their spatiotemporal properties.

In the typical MIT task, originally developed by Oksama and Hyönä (2004), all the objects in a dynamic display have distinct identities. The sequence of events in the MIT task is very similar to that of the MOT. However, the main idea behind the MIT task is that it requires the participant to form identity-location bindings for the to-be-tracked targets (i.e., knowing "what is where"). This requirement makes the MIT task more difficult than the MOT task, and the MIT more closely resembles dynamic real-life environments in which all the to-be-tracked objects have unique visual identities. In general, a participant's performance on these attentional tracking tasks usually decreases as the number of targets increase, although the observers' tracking ability depends on numerous factors (see Cavangh & Alvarez, 2005; Holcombe, 2023; Meyerhoff et al., 2017; Scholl, 2009). Generally, a participant's tracking capacity for the MIT task is smaller than for the MOT task (Horowitz et al., 2007).

One of the factors that influences performance on visual tracking tasks is effective gaze control, since eye movements are closely related to shifts in visual attention (Findlay & Gilchrist, 2003). In their review on eye tracking studies on MOT and/or MIT tasks, Hyönä, et al. (2019) concluded that, on MOT tasks, observers mainly fixate on a blank space between targets (a so-called *centroid* – a spot that is the center of gravity formed by the moving targets). In contrast, on MIT tasks, a dominant strategy is to switch the gaze between the moving targets, probably to refresh the targets' location-identity bindings. Importantly, the patterns of gaze behavior in the MOT and MIT tasks depend heavily on factors determining the action in a dynamic display (e.g., crowding, occlusions, collisions, etc.).

Performance on visual tracking tasks also depends on observers' perceptual-cognitive abilities, especially those acquired through experience in dynamic real-world situations. For instance, better tracking abilities have been demonstrated by aircraft radar operators (Allen et al., 2004) and video game players (Green & Bavelier, 2006). A special case regarding visual tracking ability is the special ability athletes have shown in relation to non-athletes, particularly athletes who practice team sports in which teammates and opponents are constantly moving around the field, court, or pitch. In general, comparative studies of MOT performance have shown that athletes outperform non-athletes. However, these findings have not been entirely consistent. Across studies, Faubert (2013) showed that professional soccer, hockey, and rugby players were better in terms of maximum speeds on 3D MOT task performance than non-athletes. Using a modified version of the MOT task, Zhang et al. (2009) demonstrated that experienced volleyball players responded faster to probed targets than non-players, but there were no differences in error rates between the two groups. Qiu et al. (2018) and Jin et al. (2020) compared elite or highly skilled basketball players with non-athletes on the MOT task and showed that both elite and highly-skilled players outperformed non-players in tracking accuracy. Lastly, Memmert et al. (2009) compared the tracking performance of expert handball players and non-athletes on the MOT task, and, from determinations of the maximum speed participants obtained when tracking the moving objects, they found no significant group differences in either accuracy or tracking speed. Others have shown that the effect of better visual tracking for athletes is likely to be moderated by their amounts of practice (Ehmann et al., 2022; Faubert, 2013; Howard et al., 2018; Qiu et al., 2018) and by the players' positions on the field (Mangine et al., 2014; Martin et al., 2017).

It is now well established that participants with extensive visual experience differ from lay people in their gaze behavior when comparisons are made in the typical visual environment of the experienced participants' expertise (see Brams et al., 2019) or sport domain (Mann et al., 2007; see also

Klostermann & Moeinirad, 2020). Yet, gaze behavior studies that employed attentional tracking paradigms comparing team sport athletes to non-athletes and/or non-team sport athletes have been limited. When Harris and colleagues (2020) compared the gaze behavior of soccer and rugby players with that of swimming, rowing, and running athletes on the two-dimensional (2D) MOT task, all participants fixated more on the targets than on a centroid and made more target switches at higher versus lower target speeds. Notably, there was no difference in gaze strategy between athletes who were experienced with real-world tracking (soccer and rugby players) and non-team sport athletes but team-sport players performed better on the MOT task than non-team-sport athletes. Researchers concluded that the better performance of team sport athletes resulted from their higher working memory capacity rather than their more efficient ability to shift overt attention between targets.

Vu and colleagues (2022) compared the gaze behavior of soccer players and non-athletes on a three-dimensional (3D) visual tracking task using virtual reality goggles to resemble real game situations. In this task, the observer stood on the pitch at the position of the central defender and looked at moving virtual teammates and opponents. Although the task was meant to mimic a real-world situation, players who were teammates and opponents differed only in their color, making this a MOT rather than a MIT task. In this paradigm, soccer players performed better than non-athletes on visual tracking, revealing some group differences in gaze behavior. Relative to non-athletes, soccer players made saccades of greater amplitude when there was a wider dispersion of target players, and soccer players spent more time fixating on target players closest to the centroid and less time fixating on “other” areas of interest (i.e., non-targets and not-centroid). Researchers suggested that the better performance of soccer players might be due to their employment of more appropriate gaze strategies; but further studies are needed to provide converging evidence for this view.

In the current study, we tested whether individuals with greater tracking experience (i.e., handball team sport players) would perform better on MOT and MIT tasks than participants without such experience. Although many previous studies used the MOT task to compare tracking abilities between athletes and non-athletes, past results from these studies have been inconclusive, and, to our knowledge, no investigators have compared these two groups on the MIT task which more closely resembles dynamic real-life visual scenes.

We theorized that if there was a superior performance by handball players relative to non-athletes on both the MOT and MIT tasks (we included the MOT task to make direct comparisons to previous research), this finding would imply either (i) a domain-general transfer of attentional tracking abilities from domain-specific situations (i.e., extensive experience of handball games on the pitch) to other visual tasks (e.g., cognitive skills tests such as MOT and MIT) or (ii) an athlete self-selection effect leading individuals with better tracking abilities to become elite athletes. We also compared the gaze behavior of handball athletes and non-athletes on the MOT and MIT to better determine whether differences in their eye movements might be the basis for group differences on tasks that mimicked dynamic real-life environments (players moving about on a handball pitch) with non-sport specific stimuli (abstract visual shapes such as circles, triangles and rectangles). If, as expected, MIT more closely resembled dynamic real-life environments, the group differences in tracking ability and eye behavior would be more noticeable in MIT than in MOT.

Method

Participants

To determine an estimated required sample size, we calculated a power analysis with G*Power 3.1 software (Faul et al., 2007), based on a mixed analysis of variance (ANOVA) with an effect size of 0.25 (based on Qiu et al., 2018), statistical power of 0.95, and an α-value of 0.05. This calculation suggested a need for 14 participants in each group or 28 participants in total. Anticipating possible participant attrition from dropouts and withdrawals, we recruited all of the handball players who volunteered and then recruited a corresponding number of non-athletes, resulting in the recruitment of and 21 highly trained handball players (17 men and 4 women; *M* age = 20.3, *SD*=1.4) and 21 non-athletes (17 men and 4 women; *M* age = 20.4, *SD*=1.4). The handball players were national league juniors and seniors playing at the first, second, and third levels; they were enrolled in athletic championship high schools or at the Wrocław University of Health and Sport Sciences (AWF). They averaged 8.35 years (*SD* = 2.6) of handball experience. The non-athletes had no experience in professional handball training or in any other sport; they were not registered players taking part in any official league competitions. All participants were given a shopping voucher worth $6.50 to compensate them for their time and effort.

Ethical Considerations

After signing informed written consent (including notice of their right to withdraw from research participation at any stage without giving any reason), the participants completed a short survey (with questions about age, sex, dominant hand, etc.) and the athletes provided their weight and height and answered questions about their sports background (position in the field, greatest achievements, participation in any perceptual-cognitive training, current state of health, and professional experience in other sports). The methods and procedures of this research protocol conformed to University of XX ethical guidelines for testing human participants, and the Research Ethics Committee of the University of XX approved the conduct of this research.

Apparatus

Both MOT and MIT tasks (stimuli presentation and behavioral data recording) were controlled and executed by the dedicated software written in the C Sharp programming language. The stimuli in both tasks were displayed on an Acer Predator 24-inch monitor (with a resolution of 1920 x 1080 px and a refresh rate of 120Hz), which was controlled by a PC (24GB RAM, Intel i7 at 3.2 GHz, Windows 10 Pro 64 bit, Nvidia GeForce GTX 6 GB graphic card). Eye tracking data were recorded with the screen-based Tobii Pro X3-120 eye-tracker (sampling rate 120 HZ, gaze accuracy 0.4 degrees, gaze precision 0.24 degrees) and the Tobii Pro Lab software in the screen recording mode. Participants were tested individually in a quiet, artificially illuminated room where they were seated 75 cm from the screen.

MOT Stimuli and Task

Ten black circles (with a radius of 85 px; 1.8° of visual angle) were displayed on a gray background within a black frame (1 600 x 1 000 pixels). At the beginning of each trial, all ten static circles were randomly displayed in different locations within the frame. Depending on the attentional load condition (see below), three, four or five circles were marked for 1500 ms with a green ring, which indicated that these circles were the targets to be tracked. After the target designation period, the green rings disappeared and the tracking phase started, with the circles moving for eight seconds. The circles moved along linear trajectories in 16 possible randomly assigned directions with constant velocities (picked randomly by the program from the range between 150 px/s and 200 px/s; ca. 3.2°-4.2°/s), and they bounced off the frame and each other. The direction and speed of each circle changed when a circle collided with another circle or with the tracking region boundary. The movement and bouncing of the circles did not follow real-world physics of motion. To avoid perceptual grouping of moving circles, two or more circles could not move in the same direction or at the same speed. After the tracking period, all circles stopped their motion, and one circle (a target in 50% or a distractor in 50% of trials) was marked with a blue ring (1500 ms). Next, all circles, including the marked one, disappeared from the screen, and two circles (85 px radius), red for the distractor answer and green for the target answer, were displayed on the horizontal midline on both sides of the centrally presented mouse cursor. In half of the trials the green circle appeared on the left side and the red circle on the right side, in the other half of the trials, this was reversed. The participant's task was to click on the circle that represented the target or the distractor, depending on the participant’s decision about the circle marked with the green ring. The response window lasted for 3500 ms, after which a feedback message was displayed for 1500 ms (‘correct’, ‘incorrect’ or ‘no response’). Then the gray screen was presented (ITI of 500 ms), and the new trial started.

MIT Stimuli and Task

The main difference between the MIT and MOT was related to the stimuli and the manner the targets and distractors were probed after the tracking period. The stimuli were 10 different colored shapes: blue rectangle, brown circle, green triangle, red pentagon, orange rhombus, purple heart, yellow diamond, white star, gray x-cross, and pink oval. Each shape had a size of 160 x 160 px (3.4° x 3.4° of visual angle). At the beginning of the trial, 10 static objects were randomly allocated within the tracking area. Depending on the attentional load condition, three, four or five objects were marked for 1500 ms with the green ring as the targets to be tracked. In each trial, a different subset of objects was randomly chosen as the targets. After the target cuing, the tracking period started, and it was run in the same manner as in the MOT task. When the tracking period was finished, all objects were covered with black circles (radius 85 px), and one circle (a hiding target in 50% of trials and a distractor in the other 50% of trials) was marked with the blue ring for 1500 ms. Then, all 10 objects were displayed in a circular array around the center of the screen where the mouse cursor appeared. Colored shapes were always displayed in that trial phase in the same positions with one additional shape (black ‘no’ symbol) at the top. The participant's task was to click on the specific color shape if that was the target hidden behind a marked black circle in the tracking phase, or to click on the black ‘no’ symbol if the marked black circle covered a distractor. After the response, the feedback message was displayed in the same manner as in the MOT task.

Procedure

Each participant performed both the MOT and MIT tasks in one session. The order of the tasks was counterbalanced across participants. In each task, participants performed three blocks of 50 trials (one block for each attentional load level) preceded by a short training block (12 trials) with the task instruction. The order of the blocks with different attentional loads was pseudo-randomized across participants. The eye-tracker was calibrated at the beginning of each block using a 9-point calibration. During the tracking task, participants were free to move or not move their eyes. There was a short break between the blocks and a longer rest period between the tasks. The entire experiment took about 120 minutes. The schematic overview of the MOT and MIT task is presented in Figure 1.

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Figure 1 about here

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Statistical and Eye Movement Analyses

The eye tracking data (sampled every eight ms) obtained from each participant for every experimental trial was divided into fixations and saccades. As the intake of visual information occurs during the fixations, our interest was only on that category of eye events. Fixation data were further assigned to one of the five areas of interest: targets, distractors, centroid, screen center or any other region. The assignment of fixations to the area of interest was conducted only if the fixation was located within this area for more than 50% of the fixation duration. Fixations shorter than 80 ms (see Oksama & Hyönä, 2016) were excluded. Each area of interest was set to be a circle of 80 px radius (1.8 degrees of visual angle). The centroid was calculated as the central point of a polygon, whose vertices were the targets' central points. For each area of interest, the average percentage of trial time spent looking at this area was calculated.

The following measures were also calculated for each trial: (a) the number of successful target visits (measured as the number of fixations on targets); (b) the number of updated targets (measured as the number of targets that were visited at least once); and (c) the average percentage of trial time spent looking at targets ranked in order of closest distance to the centroid; that is, rank 1 represented the target closest to centroid, rank 2 represented the target 2nd closest to the centroid and rank 3 represented the 3rd closest target to the centroid (in general, this measure combined indices of target-looking and centroid-looking strategies, thus allowing for more refined measurement). Moreover, we also calculated the number of fixations, and average fixation duration (ms) for each trial.

All analyses were conducted with JASP software (version 0.16.1; Love et al., 2019). Performance data (accuracy scores) for the MOT and MIT tasks were analyzed separately. We compared handball players and non-athletes on each task separately, whereas, for eye tracking data, we compared both the tasks (MOT and MIT) and the groups (athletes and non-athletes).

We used Bayesian analysis, as it is a better tool than frequentist statistics for evaluating the evidence against or in favor of the null hypothesis (Aczel et al., 2018). We used a Bayesian mixed factor analysis of variance (ANOVA) to analyze differences between multiple group means. Null and alternative hypotheses were defined for each dependent variable analysis. We used Bayes Factor (BF) to provide quantitative evidence of the alternative hypothesis relative to the null hypothesis. In other words, BF tells how much more likely one hypothesis is to be true than the other. For example, BF = 10 means that one hypothesis is 10 times more likely that the other; BF = 0.1 means that a null hypothesis of no difference between hypotheses is ten times more likely. Finally, BF = 1 means that both hypotheses (null and alternative) are equally likely. The evidence categories for Bayes factor (BF) were an adaptation of Jeffreys scheme (Goss-Sampson, 2019). Bayesian post hoc testing was based on pairwise comparisons using Bayesian t-tests with a Cauchy (0, r = 1/√2) prior.

Results

First, we analyzed accuracy scores to compare the performance levels of handball players and non-athletes on the MOT and MIT tasks. Separately, for MOT and MIT tasks, we subjected data to the Bayesian ANOVA, which was equivalent to a two-way mixed ANOVA defined by 2 Groups (athletes vs. non-athletes; between-participants) x 3 Loads (3 targets and 7 distractors [3T7D] vs. 4 targets and 6 distractors [4T6D] vs. 5 targets and 5 distractors [5T5D]; within-participants). The null hypothesis (H_0) assumed no differences between the Group and Load factors, whereas the experimental hypothesis (H_1) assumed directional differences.

MIT Task

Accuracy Data. Examination of the Q-Q plots for the MIT task suggested that the assumption of normality was not violated. The Bayesian mixed factor ANOVA determined that the data were best represented by a model that included only the Load factor. The Bayes factor (BF_{10}) was $2.3*10^{17}$, indicating decisive evidence in favor of this model when compared to the null model. On post hoc comparisons (Bayesian *t*-tests controlled for multiplicity), for the load, the adjusted posteriors showed decisive evidence for a difference between 3T7D (*M*=96.8% correct, *SD*=4.6) and 4T6D (*M*=89.5% correct, *SD*=8.1; Bayes factor: 155 958), between 3T7D and 5T5D (*M*=82.2% correct, *SD*=8.3; Bayes factor: $3.82*10^{12}$), and between 4T6D and 5T5D (Bayes factor: 17 547).

MOT Task

Accuracy Data. Examination of the Q-Q plots for the MOT task suggested that the assumption of normality was not violated. A Bayesian mixed factor ANOVA demonstrated that the data were best represented by a model that included only the Load factor. The Bayes factor (BF_{10}) was 1051, indicating decisive evidence in favor of this model when compared to the null model. On post hoc comparisons (Bayesian t-tests controlled for multiplicity), for the load, the adjusted posteriors showed moderate evidence for a difference between 3T7D (*M*=93.3% correct, *SD*=6.1) and 4T6D (*M*=91.4% correct, *SD*=5.1; Bayes factor: 3.05), and decisive evidence for differences between 3T7D and 5T5D (*M*=89.3% correct, *SD*=7.1; Bayes factor: 1729). There was no significant difference between 4T6D and 5T5D (Bayes factor: 0.97).

Eye Tracking Data

Number of Fixations. The eye tracking data for number of fixations were subjected to Bayesian ANOVA for mixed designs, with Group (handball players vs. non-athletes) as a between-subjects variable and Task (MIT vs. MOT) and the tracking Load (3 targets and 7 distractors – 3T7D; 4 targets 6 distractors – 4T6D; 5 targets and 5 distractors – 5T5D) as within-subjects variables. The null hypothesis (H_0) assumed no differences between the Group, Task, and Load factors, whereas the experimental hypothesis (H_1) assumed directional differences.

Examination of the Q-Q plots suggested that the assumption of normality was not violated. A Bayesian mixed factor ANOVA determined that the data were best represented by a model including only the Task factor (BF10 = 7332). On post hoc comparisons (Bayesian t-tests controlled for multiplicity, for the Task factor, the adjusted posteriors indicated decisive evidence for a difference between MIT (*M*=22.3, *SD*=4.4) and MOT (*M*=20.7, *SD*=3.9, Bayes factor: 1277).

Fixation Duration. The eye tracking data for fixation duration were subjected to Bayesian ANOVA for mixed designs, with Group (handball players vs. non-athletes) as a between-subjects variable and Task (MIT vs. MOT) and the tracking Load (3 targets and 7 distractors – 3T7D; 4 targets 6 distractors – 4T6D; 5 targets and 5 distractors – 5T5D) as the within-subjects variables. The null hypothesis (H_0) assumed no differences between the Group, Task and Load factors, whereas the experimental hypothesis (H_1) assumed directional differences.

Examination of the Q-Q plots suggested that the assumption of normality was not violated. A Bayesian mixed factor ANOVA demonstrated that the data were best represented by a model that included the main effects of Task and Group, and the Task*Group interaction. The Bayes factor (BF10) was $1.67*10^{20}$, indicating decisive evidence in favor of this model when compared to the null model. There was decisive evidence for the inclusion of the task in the model, strong evidence for the inclusion of the Group factor, and very strong evidence for the inclusion of the Task by Group interaction as predictors. On post hoc comparisons, (Bayesian t-tests controlled for multiplicity) for the Task factor, the adjusted posteriors showed decisive evidence for a difference between MIT (*M*=211ms, *SD*=59) and MOT (*M*=272ms, *SD*=95, Bayes factor: $7.64*10^{13}$). For the Group factor, the adjusted posteriors showed decisive evidence for a difference between handball players (*M*=261ms, *SD*=89) and non-athletes (*M*=222ms, *SD*=75; Bayes factor: 112). The Task*Group interaction is plotted in Figure 2. Mean and standard deviation values for fixation duration on MIT and MOT tasks in athletes and non-athletes groups are presented in Table 1.

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Figure 2 and Table 1 about here

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Number of Successful Target Visits. The eye tracking data for successfully visited targets were subjected to Bayesian ANOVA for mixed designs, with Group (handball players vs. non-athletes) as a between-subjects variable and Task (MIT vs. MOT) and tracking Load (3 targets and 7 distractors – 3T7D; 4 targets 6 distractors – 4T6D; 5 targets and 5 distractors – 5T5D) as within-subjects variables. The null hypothesis (H_0) assumed no differences between the Group, Task and Load factors, whereas the experimental hypothesis (H_1) assumed directional differences.

Examination of the Q-Q plots suggested that the assumption of normality was not violated. A Bayesian mixed factor ANOVA demonstrated that the data were best represented by a model including all three main effects: Group, Task, and Load. The Bayes factor (BF10) was $4.15*10^{22}$, indicating decisive evidence in favor of this model when compared to the null model. There was decisive evidence for the inclusion of the Task factor in the model, moderate evidence for the inclusion of the Load factor, and no evidence for the inclusion of the Group factor as a predictor. On post hoc comparisons (Bayesian t-tests controlled for multiplicity), for the Task factor, the adjusted posteriors showed decisive evidence for a difference between MIT (*M*=3.9, *SD*=2.5) and MOT (*M*=2, SD=1.3; Bayes factor: $3.37*10^{15}$). For the Load factor, the adjusted posteriors showed decisive evidence for a difference between 3T7D (*M*=2.5, SD=1.9) and 4T6D (*M*=3, *SD*=2.3; Bayes factor: 150) and between 3T7D and 5T5D (*M*=3.2, *SD*=2.4; Bayes factor: 603); there was no significant difference between 3T7D and 5T5D. For the Group factor, the adjusted posteriors showed very strong evidence for a difference between handball players (*M*=3.4, *SD*=2.5) and non-athletes (*M*=2.4, *SD*=1.7; Bayes factor: 92).

Number of Updated Targets. The eye tracking data for the number of updated targets were subjected to Bayesian ANOVA for mixed designs, with Group (handball players vs. non-athletes) as a between-subjects variable and Task (MIT vs. MOT) and Tracking load (3 targets and 7 distractors – 3T7D; 4 targets 6 distractors – 4T6D; 5 targets and 5 distractors – 5T5D) as the within-subjects variables. The null hypothesis (H_0) assumed no differences between the Group, Task, and Load factors, whereas the experimental hypothesis (H_1) assumed directional differences.

Examination of the Q-Q plots suggested that the assumption of normality was not violated. A Bayesian mixed factor ANOVA demonstrated that the data were best represented by a model including all three main effects: Group, Task, and Load. The Bayes factor (BF10) was $1.4*10^{33}$, indicating decisive evidence in favor of this model when compared to the null model. There was decisive evidence for including the Task and Load factors in the model, and no evidence for including the Group factor as predictors. On post hoc comparisons (Bayesian t-tests controlled for multiplicity), for the Task factor, the adjusted posteriors showed decisive evidence for a difference between MIT (*M*=2.2, *SD*=0.9) and MOT (*M*=1.5, *SD*=0.6; Bayes factor: $1.18*10^{21}$). For the Load factor, the adjusted posteriors showed decisive evidence for a difference between 3T7D (*M*=1.6, *SD*=0.7) and 4T6D (*M*=1.9, SD=0.8; Bayes factor:

$2.17*10^8$), between 3T7D and 5T5D (*M*= 2.1, *SD*=0.9; Bayes factor: $2.47*10^9$), and between 3T7D and 5T5D (Bayes factor: 106). For the Group factor, the adjusted posteriors showed strong evidence for a difference between handball players (*M*=2, *SD*=0.9) and non-athletes (*M*=1.7, *SD*=0.7; Bayes factor: 20.85).

Average Percentage of Trial Time Spent Looking at Different Areas of Interest. The eye tracking data were subjected to Bayesian ANOVA for mixed designs, with Group (handball players vs. non-athletes) as a between-subjects variable and Task (MIT vs. MOT), tracking Load (3 targets and 7 distractors – 3T7D; 4 targets 6 distractors – 4T6D; 5 targets and 5 distractors – 5T5D), and area of interest (AOI: target, distractor, centroid, screen center, other) as within-subjects variables. The null hypothesis (H_0) assumed no differences between the Group, Task, Load and AOI factors, whereas the experimental hypothesis (H_1) assumed directional differences.

Examination of the Q-Q plots suggested that the assumption of normality was not violated. A Bayesian mixed factor ANOVA demonstrated that the data were best represented by a model that included the main effects of Group, Task, Load, AOI and the Task*Load, Task*AOI, Group*AOI, Load*AOI and Task*load*AOI interactions. The data suggested decisive evidence ($BF10 = \infty$) in favor of this model when compared to the null model. There was decisive evidence for the inclusion of the Task, Load, AOI, Task by AOI interaction, and Load by AOI interaction in the model. There was very strong evidence for the inclusion of the Task and Load by AOI interaction in the model, moderate evidence for the inclusion of the Task by Load interaction, and very weak evidence for the inclusion of the Group by AOI interaction. Finally, there was no evidence for the inclusion of the Group in the model. On post-hoc comparisons (Bayesian t-tests controlled for multiplicity), for the Group factor, the adjusted posteriors showed no evidence of a difference between handballers and non-athletes. There was also no evidence for a difference between MIT and MOT Tasks. For the Load factor, the adjusted posteriors showed no evidence for a difference between 3T7D and 4T6D, but there was decisive evidence for a difference between 3T7D and 5T5D ($9.74*10^{17}$) and between 4T6D and 5T5D ($1.79*10^{18}$). For the AOI factor, the adjusted posteriors showed decisive evidence for all differences between all AOIs. The Group*AOI interactions are presented separately for each task in Figure 3. Mean and standard deviation values for the percentage of trial time spent looking at different AOIs in MIT and MOT tasks in athletes and non-athletes groups are presented in Table 2.

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Figure 3 and Table 2 about here

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Average Percentage of Trial Time Spent Looking at the Targets with Different Distances to Centroid. The eye tracking data were subjected to Bayesian ANOVA for mixed designs, with Group (handball players vs. non-athletes) as a between-subjects variable and Task (MIT vs. MOT), tracking Load (3 targets and 7 distractors – 3T7D; 4 targets 6 distractors – 4T6D; 5 targets and 5 distractors – 5T5D), and Rank of target distance to the centroid (R1 as the target closest to the centroid; R2 as the 2nd closest target to the centroid; R3 as the 3rd closest target to the centroid) as within-subjects variables. The null hypothesis (H_0) assumed no differences between the Group, Task, Load and Rank factors, whereas the experimental hypothesis (H_1) assumed directional differences.

Examination of the Q-Q plots suggested that the assumption of normality was not violated. A Bayesian mixed factor ANOVA demonstrated that the data were best represented by a model that included the main effects of Task, Load and Rank, and the Task*Rank and Load*Rank interactions. The Bayes factor (BF10) was $4.5*10^{212}$, indicating decisive evidence in favor of this model when compared to the null model. There was decisive evidence for the inclusion of the Task, Load and Rank in the model, as well as decisive evidence for the inclusion of the Task by Rank, and the Load by Rank interactions as predictors. On post hoc comparisons (Bayesian t-tests controlled for multiplicity), for the Task factor, the adjusted posteriors showed no evidence for a difference between MIT and MOT. For the Load factor, the adjusted posteriors showed no evidence for a difference between 3T7D and 4T6D, but there was decisive evidence for a difference between 3T7D and 5T5D (1448) and between 4T6D and 5T5D (38839). For the rank factor, the adjusted posteriors showed decisive evidence for a difference between R1 and R2 ($6.26*10^{33}$), between R1 and R3 ($7.38*10^{48}$), and between R2 and R3 ($2.13*10^{28}$). The interaction task*rank is presented in Figure 4. Mean and standard deviation values for the percentage of trial time spent looking at targets with different distances to the centroid in MIT and MOT tasks are presented in Table 3.

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Figure 4 and Table 3 about here

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Summary data related to variables and interactions favored by the relative strength of evidence (in Bayesian Analysis) for behavioral and eye tracking data are presented in Table 4.

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Table 4 about here

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Summary of Results

Attentional load affected performance accuracy for both participant groups on both the MIT and MOT tasks. Performance accuracy decreased with the increasing number of targets, even though the number of distractors decreased. Interestingly, this gradual decrease in performance accuracy was not as evident on the MOT task as on the MIT. This finding indicates that the increase in attentional load had a greater effect on the MIT task than the MOT task. However, most notably for the present study, there was no difference in performance accuracy between athletes and non-athletes, on either the MIT or MOT tasks.

Analyses of eye tracking data revealed that the number of eye fixations was affected only by the task. For both groups, regardless of attentional load, observers made more fixations when performing the MIT task than the MOT task. Yet, the fixations were generally shorter on the MIT task than on the MOT task (regardless of the attentional load). The number of successful target visits was affected by the attentional load (an increase as a function of the number of targets, regardless of the task and the participant group) and by the task (higher in the MIT than in the MOT task, regardless of the attentional load and the participant group). An analogous pattern of results was obtained for target updating. These findings are consistent with those of Oksama and Hyönä (2016).

In terms of the average percentage of trial time spent looking at different areas of interest, participants on both tasks spent most of their trial time looking at some position on the background of the screen that was neither the centroid nor the screen center. The second most fixated area were the targets; and participants looked at them more on the MIT than MOT task. The third most looked-at AOI on both tasks were the distractors; participants looked at them more on the MOT task than on the MIT task. Finally, participants spent the least amount of time looking at the centroid and the screen center on both tasks. Regarding the time spent looking at the targets with different distances to the centroid, the most important finding was that, on the MOT task, participants looked more at the target closest to the centroid than they did on the MIT task.

We also observed differences in eye movements between athletes and non-athletes. First, on average, handballers generally made longer fixations than non-athletes on both tasks. Moreover, handballers visited targets with their eyes more often than non-athletes, regardless of the attentional load and the task. Regarding the percentage of trial time spent looking at different areas of interest, in MOT athletes spent more time looking at the targets than non-athletes.

Discussion

In the present study, we aimed to compare the cognitive performance and gaze behavior of extensively trained athletes from a team ball sport (i.e., handball) and non-athletes on multiple object tracking (MOT) and multiple identity tracking (MIT) tasks. Although there are previous studies on differences between athletes and non-athletes on the MOT task, to our knowledge, no such studies have been conducted using the MIT task.

We found attentional tracking performance to be slightly better on the MOT task than on the MIT task for both participant groups, and participant performance deteriorated with an increase in attentional load on both the MOT and MIT tasks (although the effect of attentional load was more pronounced on MIT than on MOT). Our main finding was of no significant differences in attentional tracking accuracy between athletes and non-athletes either on the MOT or the MIT task. Although some others have demonstrated that athletes performed better on attentional tracking on the MOT (e.g., Faubert, 2013; Zhang et al., 2009; Qiu et al., 2018; Jin et al., 2020), this has not always been found in past research (e.g., Memmert et al., 2009; Zhang et al., 2009). There has been a long-lasting claim that athletes are no better than non-athletes at basic visuo-perceptual tasks (e.g., Abernethy et al., 1994; West & Bressan, 1996; Wood & Abernethy, 1997). However, this conclusion might be a consequence of different methods used across studies. In fact, in a recent review, Hodges and colleagues (2021) argued that cognitive skill differences between athletes and non-athletes were best demonstrated when sport-specific stimuli or tests were used. Adopting this line of reasoning, we may have failed to find differences between athletes and non-athletes in attentional tracking because the stimuli we used were not sport-specific (they were abstract visual shapes rather than players moving about on the court). This perspective is also supported by Kalen et al.'s (2021) review in their conclusion "that tests using sport-specific stimuli were considerably more successful in differentiating higher- and lower skilled athletes than tests with non-sport-specific stimuli" (p.1300). The sport-specificity problem arises when one of the sensory information sources (in our case vision) is altered or removed such that learning and performance is degraded (e.g. Czyż et al. 2015; Keetch et al. 2008). In our experiment, athletes (i.e., experienced handball players) did not perform the task in their normal visual environment (i.e. on a handball court) and the tracked multiple objects were not other players (as would be the case in game play), but were meaningless geometrical shapes. Thus, the visual conditions in which athletes were performing on the MIT and MOT tasks in the lab differed from the MIT and MOT tasks performed during a game.

There are other potential reasons for our finding of no significant group differences in performance accuracy on the MOT and MIT tasks. First, the speed of our moving objects was slow on both tasks (approximately 3°- 4°/second), compared to that of other studies (e.g., Harris et al., 2020). Jin et al. (2020) showed that basketball players were better than non-athletes when objects moved with higher speeds on the MOT task. Second, an increasing number of young people (who do not train professionally in any sport) now use mobile phones daily (for watching short videos and playing mobile video games), perhaps providing them more visual training with dynamic displays than might have been true of control participants in past studies.

Our eye tracking results suggest that the target-switching strategy used by both groups on the MIT task was the dominant eye-movement strategy. Participants frequently visited targets with their eyes and updated their visual experience more often on the MIT than on the MOT task. Additionally, although in both tasks, participants spent very little time looking at the centroid while they spent much more time looking at the targets, the time spent looking at the targets was higher on the MIT than on the MOT task. This target-switching strategy on the MIT task is consistent with Hyönä, et al's (2019) review (see also Oksama & Hyönä, 2016). It has been argued that the difference in eye movement strategies on the MOT and MIT is due to the identity information being visually present in MIT but not in the MOT (Wu & Wolfe, 2018). Although this seems plausible, recent investigators (Lukavsky & Meyerhoff, 2023) reported distinct tracking strategies on the MOT and MIT, with the MIT characterized by a target switching strategy, while target identities were hidden on the MIT.

On the other hand, our eye tracking results indicated that, on the MOT task, participants did not use the centroid-looking strategy, as suggested by Hyönä et al. (2019). Our participants in both groups spent very little time looking at the centroid, whereas they looked more at the targets, distractors, and other AOIs on the MOT task. Possibly participants on the MOT task tracked one target with their gaze while keeping the other targets in their peripheral vision (see Zelinsky & Neider, 2008; Oksama & Hyönä, 2016). Moreover, on the MOT task, participants (from both groups) tended to look more at the target closest to the centroid than they did on the MIT task (see also Vu et al., 2022). Compared to the constant mental computation of the centroid between the targets, it is more cost-efficient to localize and track the target closest to the middle between the targets (Oksama & Hyönä, 2016; Vu et al., 2022). Maybe the centroid-looking strategy is more likely to occur in conditions where there is no risk that targets will be 'swapped' with the distractors (this is when moving objects do not collide or occlude each other) and when targets move at faster speeds. Here, the moving objects bounced off each other, and the object speed was relatively slow.

One other issue should be noted here. Li et al. (2019) found that participants' eye movement strategies on the MIT task, with colored circles as the stimuli, were similar to those that participants adopted on the MOT task, with black circles as the stimuli. The participants tended to look more at areas between the targets. In our study, although the MIT object identities were based on color (and shapes), the participants did not look at areas between the targets to the same extent that they did on the MOT task. In Li and colleagues' study, the identities differed only in color. It seems that when both color and shape are involved (as in our study), it is more difficult to track different identities in objects in the periphery (while looking at areas between the targets). Thus, the target objects needed to be updated with the use of frequent target fixations.

As there were no differences in performance between handballers and non-athletes (as discussed earlier), it is no surprise that there were no significant differences in general eye-movement strategies used by these groups on either task. However, some differences in gaze behavior between athletes and non-athletes were still observed. Handballers' fixations during task performance were generally longer than those of non-athletes on both tasks than were those of non-athletes. This result may indicate that handball players achieved the same level of performance as non-athletes, but, perhaps, with a lower level of effort. This interpretation is consistent with the theory of "neural efficiency" in sport psychology (Li & Smith, 2021). Moreover, athletes looked at targets more often and updated them more often than non-athletes. Given that there were no significant differences in the level of performance across the two groups on both tasks, these findings suggest that handballers are more efficient in their ‘use’ of their eyes than are non-athletes. Handballers seem capable of fixating at one target with effective simultaneous peripheral tracking of other targets. Moreover, it seems that this target-oriented gaze behavior (probably practiced extensively during handball games where attentional-perceptual visual processing resembles more the requirements of the MIT task than those of the MOT task) is used by handballers in all attentional tracking situations, as athletes spent more time than non-athletes looking at the targets even in the MOT task.

Limitations and Directions for Further Research

The main limitations of our study were the stimuli and tasks we used within the MOT and MIT tasks. Our use of abstract visual shapes as the objects that participants considered as targets after the tracking period were typical of those commonly used in laboratory settings for studying basic perceptual-attentional processes, but they were far from the real-life visual scenes and events encountered by players on the pitch or court. However, requiring tasks to be more and more like actual sports play to detect differences between athletes and non-athletes’ perceptual-cognitive skills may only demonstrate how small these differences can be (except for the sport skills themselves). Furthermore, as suggested in the review by Klostermann and Moeinirad (2020), when studying perceptual-cognitive differences between athletes and non-athletes (and related to these, differences in gaze behavior), researchers should focus more on investigating gaze behavior coupled with action, rather than just averaging basic eye tracking measures. However, because of the nature of the tasks used in our experiments, it was impossible to employ such methods. In sum, to properly study perceptual-cognitive differences between athletes and non-athletes, future experiments should use stimuli and tasks that resemble more real-life pitch/court/field situations, and the eye-tracking measures should be based more on perception-action coupling.

Conclusions

Our results in the present study indicate that tasks designed for probing basic cognitive skills in dynamic visual environments (multiple object tracking and multiple identity tracking) did not significantly differentiate attentional-cognitive abilities of trained athletes and non-athletes. Although there were no significant group differences in performance on the MOT and MIT tasks, we found modest but significant differences in gaze behavior between the two groups. Most importantly, athletes with ample experience in team ball sports, used a more target-oriented eye movement strategy during attentional tracking and seemed more efficient in their performance. Future studies should examine patterns of eye movements based on a perception-action link using stimuli and tasks that are specific to the practiced sport. Of course, it must also be noted that if it is necessary to use tasks that are very similar to the sport tasks themselves to differentiate athletes from non-athletes, meaning that there may be no significant real difference between these groups apart from those sports skills. Future research in this domain will also benefit from utilizing larger participant sample sizes capable of detecting small effect sizes without introducing Type 1 error.

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Table 1. Mean (M) and standard deviation (SD) values for fixation duration (in milliseconds) in MIT and MOT tasks in athletes and non-athletes groups.

	MIT	MOT
Athletes	*M* = 222.61 *SD* = 56.63	*M* = 300.56 *SD* = 98.64
Non-athletes	*M* = 200.41 *SD* = 59.68	*M* = 243.8 *SD* = 82.99

Table 2. Mean (M) and standard deviation (SD) values for percentage of trial time looking at different AOIs in MIT and MOT tasks in athletes and non-athletes groups.

	MIT		MOT	
	Athletes	Non-athletes	Athletes	Non-athletes
Target	*M* = 32.07 *SD* = 11.89	*M* = 29.8 *SD* = 13.91	*M* = 22.58 *SD* = 8.3	*M* = 18.64 *SD* = 6.25
Distractor	*M* = 4.93 *SD* = 2.33	*M* = 5.09 *SD* = 2.05	*M* = 7.24 *SD* = 2.41	*M* = 8.34 *SD* = 2.55
Centroid	*M* = 2.15 *SD* = 1.29	*M* = 1.83 *SD* = 1	*M* = 1.7 *SD* = 0.96	*M* = 1.61 *SD* = 0.94
Screen center	*M* = 2.15 *SD* = 1.29	*M* = 2.4 *SD* = 1.41	*M* = 2.61 *SD* = 1.12	*M* = 2.95 *SD* = 1.7
Other	*M* = 41.85 *SD* = 26.29	*M* = 42.81 *SD* = 28.67	*M* = 46 *SD* = 29.94	*M* = 47.81 *SD* = 31.46

Table 3. Mean (M) and standard deviation (SD) values for percentage of trial time spent looking at the target closest to centroid (R1), the 2nd closest target to the centroid (R2), and the 3rd closest target to the centroid (R3) in MIT and MOT tasks.

	MIT	MOT
R1	*M* = 41.18 *SD* = 11.79	*M* = 47.73 *SD* = 13.76
R2	*M* = 29.45 *SD* = 6.11	*M* = 29.73 *SD* = 7.52
R3	*M* = 20.46 *SD* = 8.1	*M* = 17.12 *SD* = 9.46

Table 4. Summary of Variables and Interactions Favored by the Relative Strength of Evidence (in Bayesian Analysis) for Behavioral and Eye Tracking Data.

Type of data	Dependent variable	Evidence-favored variables	Evidence-favored interactions
Behavioral data			
	MIT accuracy	Load	---
	MOT accuracy	Load	---
Eye tracking data			
	Number of fixations	Task	---
	Fixation duration	Group; Task	Group * Task
	Number of successful target visits	Group; Task; Load	---
	Number of updated targets	Group; Task; Load	---
	Avg. % of trial time spent looking at different AOIs	Group; Task; Load; AOI	Task * Load; Task * AOI; Group *AOI; Load * AOI; Task * Load * AOI
	Avg. % of trial time spent looking at targets with different distances to centroid	Task; Load; Rank	Task * Rank; Load * Rank

Note. Load – tracking load (3 targets and 7 distractors, 4 targets and 6 distractors, 5 targets and 5 distractors); Task – multiple object tracking (MOT) and multiple identity tracking (MIT); Group – handball players and non-athletes; AOI – area of interest (target, distractor, centroid, screen center, other); Rank – rank of target distance to centroid (R1 as the target closest to the centroid; R2 as the 2nd closest target to the centroid; R3 as the 3rd closest target to the centroid).

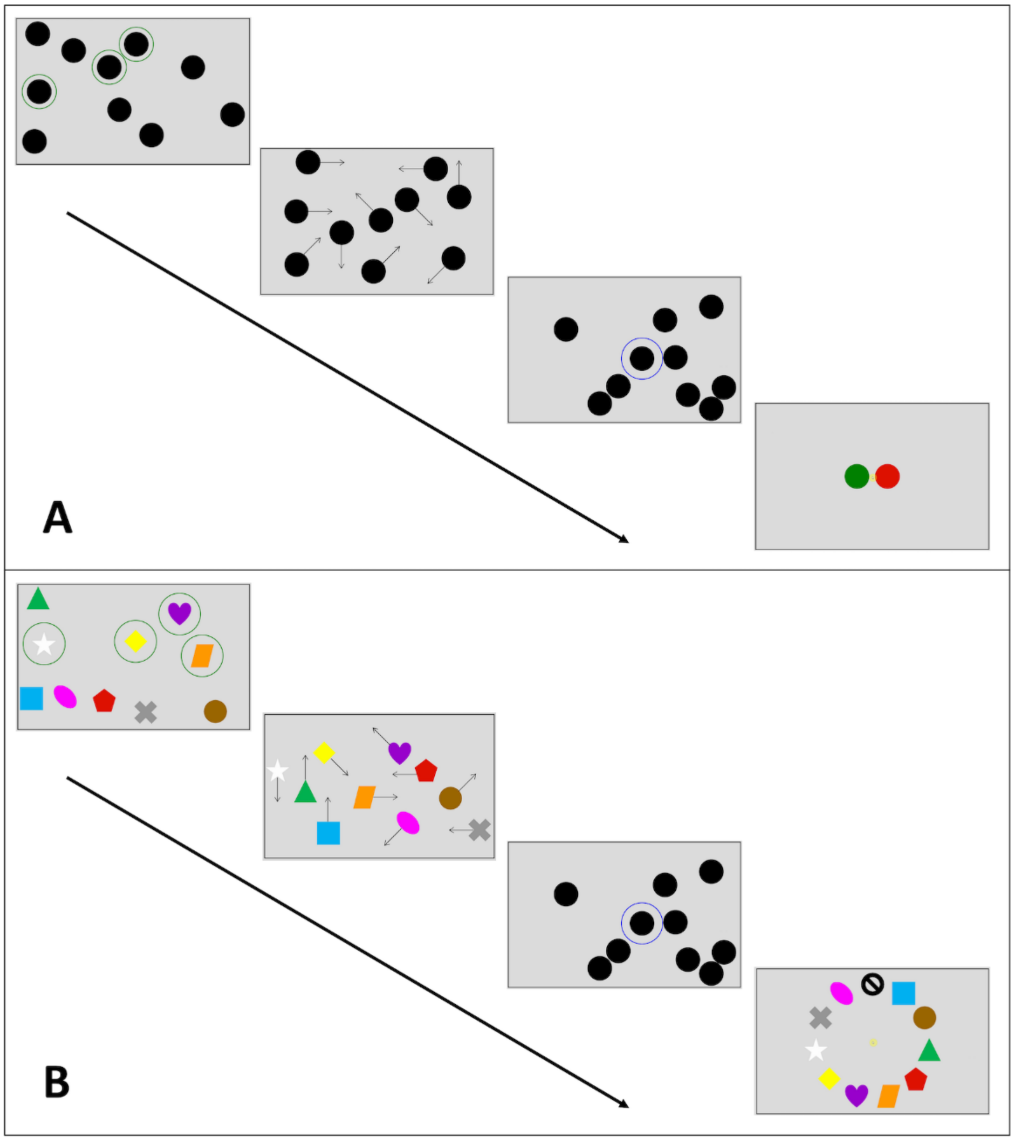
List of figure titles:

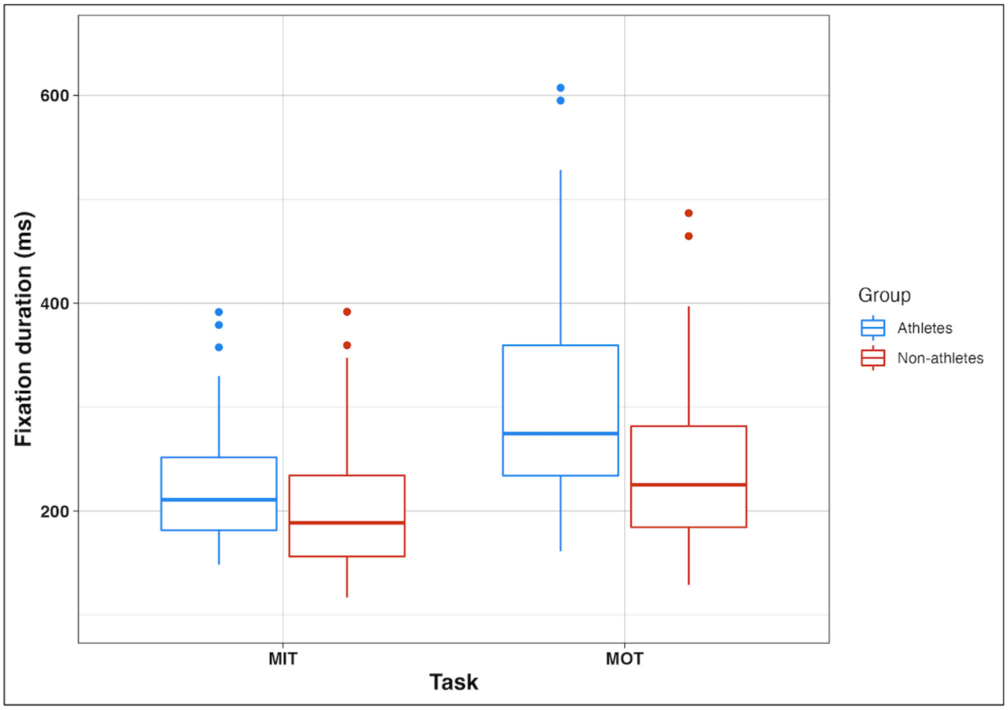
Figure 1. Schematic Overview of the MOT Task (A) and the MIT Task (B).

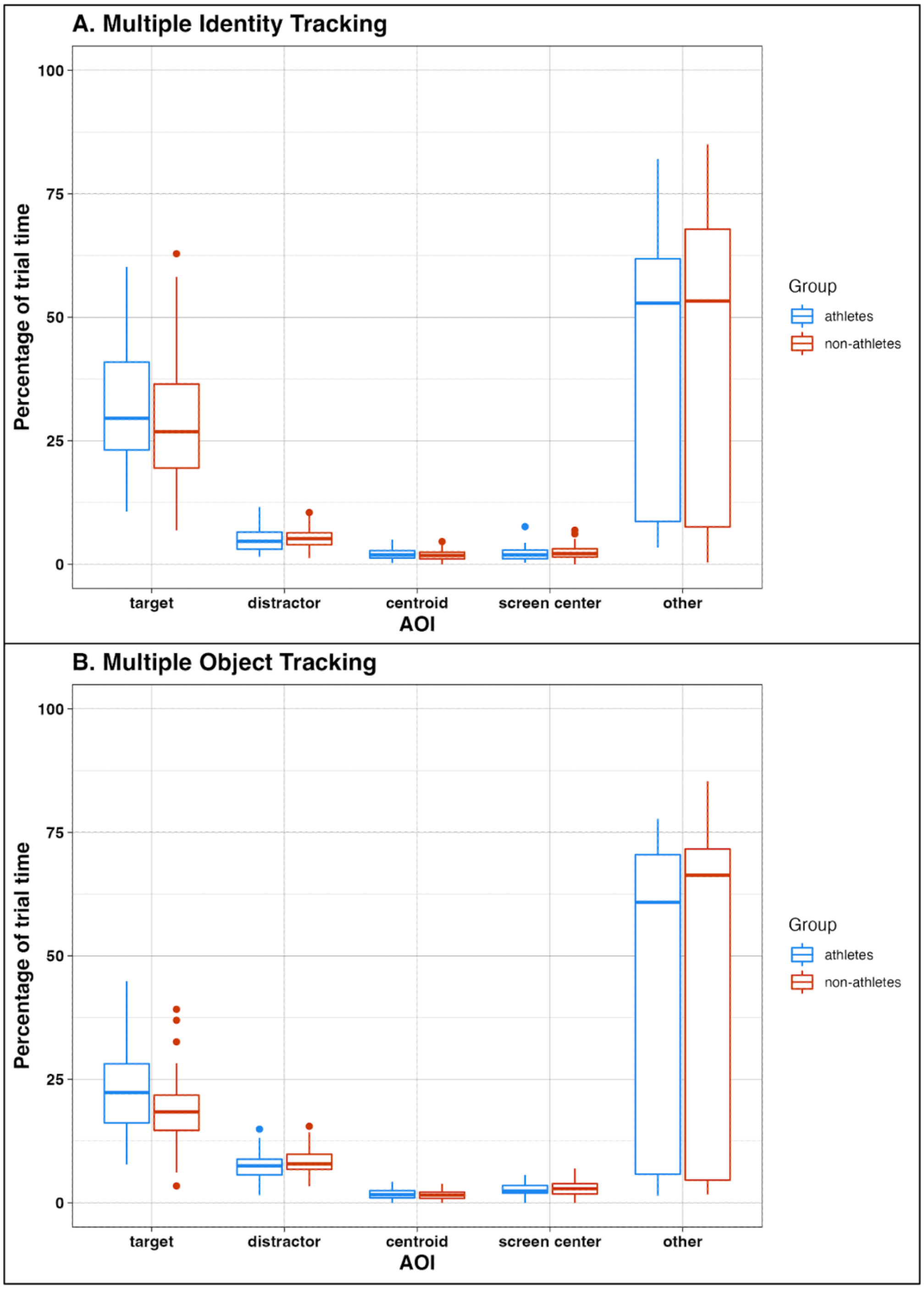
Figure 2. Mean Fixation Duration in MIT and MOT Tasks in Athletes and Non-athletes Groups.

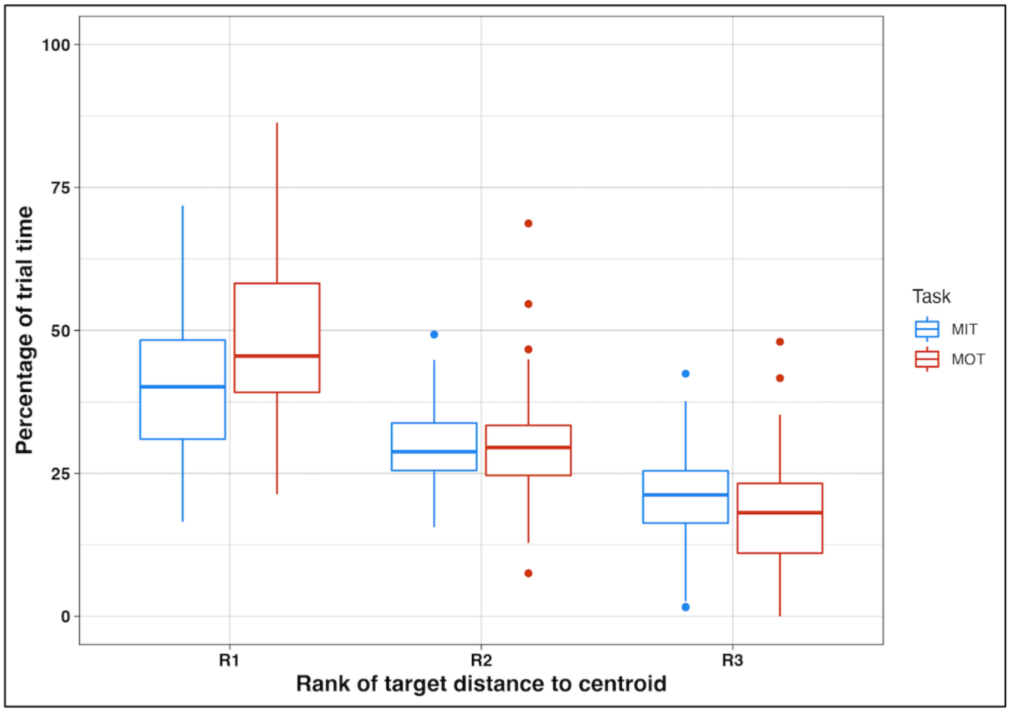
Figure 3. Percentage of the Trial Time Spent Looking at the Targets, Distractors, Centroid, Screen Center, or Other Areas on the Screen in Athletes and Non-athletes Separately for MIT (A) and MOT (B) Tasks. The time is calculated from fixation durations on the aforementioned areas of interest. The rest of the trial time participants spent on saccades, blinks, looking out of the screen.

Figure 4. Percentage of the Trial Time Spent Looking at the Target Closest to Centroid (R1), the 2nd Closest Target to the Centroid (R2), and the 3rd Closest Target to the Centroid (R3) in the MIT and MOT Tasks.


A
B


600
400
200
Fixation duration (ms)
MIT
MOT
Task
Group
Athletes
Non-athletes


A. Multiple Identity Tracking
Percentage of trial time
0
25
50
75
100
target
distractor
centroid
screen center
other
AOI
Group
athletes
non-athletes
B. Multiple Object Tracking
Percentage of trial time
0
25
50
75
100
target
distractor
centroid
screen center
other
AOI
Group
athletes
non-athletes



100
75
50
25
0
Percentage of trial time
R1
R2
R3
Rank of target distance to centroid
Task
MIT
MOT