Young Basketball Players' Multiple Object Tracking Skills Were Unaffected by Stroop-Induced Mental Fatigue

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Abstract

We aimed to examine the acute effect of mental fatigue on young basketball players' three-dimensional multiple object tracking (3D-MOT) skills. Our participants were 12 adolescent basketball players (*M* age = 16.66, *SD* = 1.87 years; *M* years of practice = 2.66, *SD* = 1.07 years). In nine lab visits, we used visits 1 to 7 to familiarize participants with 3D-MOT, a subjective scale of mental fatigue, and a Stroop task involving mental set shifting. In the last two visits, participants performed in both experimental (EXP) and control (CON) conditions that were presented in randomized order. In the EXP condition, participants performed 3D-MOT pre- and post-60 minutes of induced mental fatigue; in the CON condition, they watched a documentary. After each condition, B participants performed the National Aeronautics and Space Administration Task Load Index (NASA-TLX). 3D-MOT performance measures were the "score" and "fastest trial score success." The response time on the Stroop tasks increased throughout the mental fatigue inducement in the experimental condition ($p = 0.0037$). The NASA-TLX responses were higher following the EXP condition than following the CON condition for mental demand, temporal demand, and performance (all $ps < 0.05$). Still, there were no significant EXP versus CON differences on the 3D-MOT performance indicators.

Keywords: cognition; perceptual-cognitive skill; team sports

Introduction

Interceptive sports, like basketball, are activities that require coordination between an object (e.g., a ball) and an athlete's body/part , involving a dynamic context and well-developed perceptual-cognitive skills (Dong et al., 2022). These skills allow the player to evaluate and integrate sensory information accompanied by previous tactical knowledge, resulting in efficient interactions with the environment (Hodges et al., 2021; A. M. Williams et al., 2012). Furthermore, visual perception is often the perceptual-cognitive skill on which most sports, including basketball, are central (Sirnik et al., 2022a). This coordination skill has been considered a main contributing factor to successful performance in team sports, including basketball (Liu et al., 2020).

Visual search behavior refers to alternations between fixations and saccades (i.e., eye movements), and it seems essential to overall performance in basketball. The game of basketball demands that players observe hard-to-predict movements by teammates and opponents, and that they identify and track empty spaces, and simultaneously maneuverer into a shooting position to shoot the ball into the basketball hoop (Sirnik et al., 2022b; Vaeyens et al., 2007). These requirements make even young basketball athletes good candidates for a laboratory examination of the effects of mental fatigue on multiple object tracking.

Eye movements must be controlled by a time-efficient search strategy (Morgan & Patterson, 2009). Eye movements are commonly assessed by eye-movement recording systems (A. Mark Williams & Ericsson, 2005), a 360º multiple object tracking (MOT) (Ehmann et al., 2022), and a three-dimensional MOT (3D-MOT) tool in a training strategy to improve perceptual-cognitive skills in athletes from different ball sports (Romeas et al., 2016, 2019) and in non-sport-specific outcomes (Parsons et al., 2016).

Interestingly, the speed at which multiple objects can be visually tracked is correlated with specific abilities required in basketball, such as assists (i.e., actions to pass the ball to the teammate who scores a basket) and steals (i.e., steals of the ball by a defensive player through an interception) (Jin et al., 2020; Mangine et al., 2014). In this way, the velocity at which athletes can perform correctly in the MOT seems to be the most important indicator of task success. Indeed, Faubert (2013a) showed that the speed threshold in the 3D-MOT task could differ for athletes by their competitive level. Thus, other indicators related to velocity in the task might indicate an improvement or decrease in the MOT performance (e.g., scores and maximum speed reached). However, the velocity itself is not enough to entirely explain performance, but an increase in the visual search demands, visual challenges, and the rate of interactions that high speeds create also play a role (Faubert & Sidebottom, 2012). Therefore, multiple indicators should be used to measure performance during the MOT task.

Considering the importance of visual tracking skills for basketball, psychobiological states of readiness or fatigue might influence this skill and lead athletes to worse or better performance. Studies have shown that varying levels of players' mental fatigue might differentially affect basketball performance (Cao et al., 2022). Mental fatigue is a psychobiological state characterized by tiredness, lack of energy, and impaired cognitive performance after an exposure to a task requiring extensive cognitive effort (Marcora et al., 2009). A recent systematic review revealed that free-throws, three-point shots, turnovers, and decision-making were impaired by mental fatigue (Cao et al., 2022). Also, a recent study showed that basketball players' visual performance, as measured by eye-tracking, was changed by this fatigue state with resultant impairment in some perceptual-cognitive skills (L. de S. Fortes et al., 2022). In most past experiments, mental fatigue was induced by a computerized cognitive task for at least 30 minutes (Van Cutsem et al., 2017); in others, mental fatigue was induced by prolonged use of social media or videogame (Faro et al., 2022; Fortes et al., 2020, 2022). However, no investigator has yet studied the effect of mental fatigue on MOT outcomes. Yet, 3D-MOT is more accessible and easier to implement in athletes' routines than is the more often-studied eye-tracking outcome measure, and it is important to isolate the specific skills that may be affected by mental fatigue.

Thus, we aimed to examine the acute effect of mental fatigue by using basketball players' MOT skills with the 3D-MOT assessment tool. We selected basketball players for this test because of the high interceptive demands of this sport and our expectation that athletes' object-tracking skills would be particularly sensitive to the effects of mental fatigue, even in young players. Previous findings also revealed changes in visuomotor skills for mentally fatigued basketball players (Faro et al., 2022). We hypothesized that MOT skill parameters (e.g., threshold speed and score) would be impaired by exposure to mental fatigue.

Method

Participants

Fourteen young male basketball players from one school team voluntarily participated in this study. Since the sample of the players was limited in size, it was not possible to recruit them randomly; hence we recruited a convenience sample. Two athletes were excluded from the analysis because they did not complete the familiarization sessions, leaving 12 athletes (*M* age =16.66, *SD* =1.87 years; *M* years of practice = 2.66, *SD* = 1.07) whose data could be used for these analyses. These athletes came from the same team that competed at state and regional levels; they trained four times per week for ~1.5 hours per session. The training session involved one hour of technical-tactic drills and 30 minutes of physical training. Participants were informed of the study's procedures and of their rights to withdraw from the study, and they gave their informed assent. Parents or legal guardians of all participants also gave their informed consent. The study protocol followed the World Medical Association's Declaration of Helsinki and the study received approval from Ethics Committee of the Federal University of Paraíba with the registration number: (42205621.4.0000.5188).

Study design and Procedure

This is a crossover study, with the order of experimental and control conditions randomized. The study was divided into two phases with eight visits (see Figure 1). First, participants underwent 15 familiarization sessions to achieve performance stabilization of 3D-MOT in the NeuroTracker platform (NeuroTracker, Montreal, Canada). We followed Faubert (Faubert, 2013) with this procedure, the familiarization phase was split into five non-consecutive days in which there were three sessions per day, each separated by 40 minutes. During the break between session trials, the athletes remained in a room with no access to smartphones or books or a means by which they might self-induce cognitive load. They were allowed to make conversation with each other. In the second phase, we provided one session in which we familiarized participants with the survey instrument used to acquire subjective ratings of mental fatigue (i.e., National Aeronautics and Space Administration Task Load Index; NASA-TLX) and with a Stroop task (Martin et al., 2016) to induce mental fatigue. Then, participants underwent two visits scheduled one-week apart in which they experienced either the experimental condition (EXP) or the Control condition (CON). In the EXP, participants performed the 3D-MOT and underwent mental fatigue inducement for 60 minutes (i.e., engaged in the Stroop task). In the control condition (CON), participants underwent similar procedures but, in place of the Stroop task mental fatigue inducement, they watched a one-hour documentary film. Immediately after the experiment (i.e., post-experiment), the participants answered the NASA-TLX and performed the 3D-MOT again. Participants were instructed not to use caffeine, social media, physical exercise, or other cognitively or physically demanding activity at least six hours before experimental conditions. Before starting the treatment procedures, the participants answered a pre-trial checklist confirming that they had followed these recommendations. All trials lasted about 90 minutes. It is important highlight that previous studies about mental fatigue also used similar experimental design (e.g., mental fatigue and control conditions)

Figure 1 here

3D Multiple Object Tracking (3D-MOT)

The procedures of 3D-MOT application followed previous work on MOT and team sports athletes (Romeas et al., 2016). A 55-inch projection screen was used to display 3D-MOT CORE version 1.16.6 mode (NeuroTracker, Montreal, Canada). The participant was seated comfortably in a chair at 2.70 meters from the screen. The task required the participant to follow four of eight yellow 3D spheres that moved for eight seconds on the screen. That is, the animation of the MOT task was rendered and showed depth cues in relation to the sizes of the spheres and dimensions of the cube. The spheres that must be followed were highlighted for two seconds before they started to move. When the objects stopped, they were numbered, and the participant was required to say the numbers corresponding to the spheres highlighted at the beginning of the trial. The participants spoke the numbers verbally, and the researcher clicked on the spheres with the numbers judged as correct by the participant. When the answer was correct, (i.e., correctly selected all four balls) the speed of the subsequent trial increased, otherwise the speed decreased. For the first attempt, the speed at which the balls moved was standardized to 68 cm*s-1.). The participants performed 20 trials in each application. The "score" (i.e., represented the average speed of the last four attempts) and the "fastest trial score success" (i.e., maximum speed reached during attempts) as the participant's 3D-MOT performance indicators.

National Aeronautics and Space Administration Task Load Index (NASA-TLX)

To acquire subjective ratings of mental fatigue for the extent to which we had induced mental fatigue, we used the NASA-TLX. This questionnaire has six domains: mental demand, physical demand, temporal demand, performance, effort, and frustration. However, considering that our experiment used no physical task, we excluded the physical demand and effort domains from this survey. Each domain had a specific related question referring to that activity. Thus, the scale was applied only after each experimental condition. Each question was followed by a line with 20 markers that limited where the participant should make their response. The corresponding marking was multiplied by five to calculate the final score. The participants were asked to mark a point on the line corresponding to the state of their mental fatigue for each domain at that moment. Previous studies similarly used the NASA-TLX to identify the domains affected by mental fatigue (Van Cutsem et al., 2019, 2022)

Treatment

EXP - Mental Fatigue. The modified Stroop task (Martin et al., 2016) was used to induce mental fatigue in the experimental (EXP) condition of the study. Only incongruent stimuli were used. Participants were instructed to respond based on the word's color and ignore its meaning. The colors yellow, blue, green, and red were used and each had a corresponding motor response on the keyboard (i.e., "A", "D", "J", and "L", respectively). To avoid delay, participants were instructed to position both hands on the keyboard. The letters on the keyboard were colored to match the corresponding letter color, as shown in Figure 2. The task was administered in four blocks of 15 minutes each, for a total duration of 60 minutes. Participants were instructed to respond as quickly and accurately as possible. The task was created and administered using the PsychoPy software (version 2021.2.3, GNU General Public License) and presented on a 17-inch screen in a silent, temperature-controlled room with low luminosity, and overseen by the lead researcher.

Documentary. In the control condition (CON), participants watched an emotionally neutral documentary (Science Mysteries - A Journey to the Center of the Earth, audio in Portuguese, without subtitles) on a 17” inch screen, in a temperature-controlled at 16º-18ºC and with low luminosity, only with the presence of one researcher.

Statistical Analysis

Data normality was tested by Shapiro-Wilk and the homogeneity of variances was tested by Levene test. A 2-way mixed effects, average of measurements, and consistency agreement Intraclass Coefficient Correlated (ICC) and 95% interval of confidence (95%IC) were calculated for each variable, using the data from the three last trials (i.e., day 5) of phase 1. The qualitative ICC classification was >0.90 “excellent”, 0.75-0.90 “good,” 0.50-0.75 “moderate”, and <0.50 “poor” (Koo & Li, 2016). The difference in the response time of Stroop task blocks was tested using the Friedman ANOVA by ranks test since the data for this variable did not present a normal distribution. The NASA-TLX response was compared with Wilcoxon test. The remaining variables were tested using repeated measures ANOVA two-way (Time x Conditions) for analyzing main effects (Condition, Time) and any interaction effect of Condition X Time on the two times for 3D-MOT skills. If a significant difference was identified, the Bonferroni post hoc procedure was used for pairwise comparisons. We calculated partial eta squared (ηp^2) to measure the effect size (ES) and interpreted effect sizes as small: 0.01; moderate: 0.09; large: 0.25, as suggested by Mesquita et al. (Mesquita et al., 2019). Statistical procedures were performed using the Statistical Package for the Social Sciences software (SPSS, version 20.0; IBM Corp., Armonk, NY, USA). We set statistical significance at $p < 0.05$.

Results

NASA-TLX. Table 1 shows the participants' responses on the NASA-TLX domains for each experimental condition. Except for frustration, all domains of NASA-TLX were significantly different between conditions. Participants reported the mental demand to be 32% greater in the mental fatigue condition than in the control condition.

Table 1 here

The response time on the Stroop task in the mental fatigue condition significantly increased over time (p=0.0037; Fr= 13.300; η_{p^2}=0.337). These differences occurred between block 1 *vs* block 3 (p =0.021; Fr=12.000; η_{p^2}=0.406) and between block 1 *vs* block 4 (p=0.004; Fr= 8.333; η_{p^2}=0.500). However, there was only a tendency toward a significant difference in Stroop accuracy over time (p=0.053; F= 2.830; η_{p^2}= 0.205) (Figure 2).

Figure 2 here

3D-MOT.

The ICCs were "good" for Score on the 3D-MOT (ICC=0.806; 95%IC=0.487-0.939; p=0.001) and Fastest on the 3D-MOT (ICC=0.765; 95%IC=378-0.926; p=0.002), indicating acceptable reliability on these measures. The 3D-MOT variable remained unaltered after both conditions (see Figure 3).

While there was a significant main effect of Time on the 3D-MOT Score ($F_{(1,11)}$ = 7.084, p = 0.027 η_{p^2} = 0.392), follow-up analyses did not show any separate Time effect in either the EXP condition ($F_{(1,11)}$ = 3.122; p = 0.105, η_{p^2} = 0.221) or the CON condition ($F_{(1,11)}$ = 2.511, p = 0.141, η_{p^2} = 0.186); and there was no significant Time x Condition interaction effect ($F_{(1,11)}$ = 0.014; p = 0.097, η_{p^2} = 0.001). Similarly, there was no Condition main effect for 3D-MOT Score ($F_{(1,11)}$ = 0.110; p = 0.747; η_{p^2} = 0.010).

For 3D MOT Fastest, there was no significant main effect of Time ($F_{(1,10)}$ = 1.509, p = -.232, η_{p^2}=0.106), no significant main effect of Condition ($F_{(1,10)}$ = 0.092, p = 0.764, η_{p^2} = 0.008, and no significant Time x Condition interaction effect ($F_{(1,10)}$ = 0.260, p =.615, η_{p^2} = 0.193).

Figure 3 here

Discussion

We aimed to assess the potential effect of mental fatigue on basketball players' MOT performance. The response time on Stroop tasks increased throughout the mental fatigue experimental condition, and the participants' subjective feelings of mental demand (as measured by the NASA-TLX) were higher when they were in the mental fatigue condition compared to the control condition. Still, their performance across these two EXP and CON conditions, as indicated by the 3D-MOT, were not significantly different; and this is in contradiction to our initial hypothesis.

Previous studies have shown that 3D-MOT was able to distinguish visual search learning among professional, amateur-elite, and non-athletes (Faubert, 2013b) and that engagement in it was associated with improved passing decision-making accuracy in soccer players (Romeas et al., 2016). Since previous studies showed that the outcomes of the 3D-MOT measures (i.e., visual search behavior) were impaired by mental fatigue (L. de S. Fortes et al., 2022; Smith et al., 2016), we expected but did not find, a decline in 3D-MOT performance following the cognitive effort our participants experienced on the Stroop task. Considering the original aim for which this tool was created (i.e., training the visual search behavior), maybe a transitive state like mental fatigue did not affect the 3D-MOT performance. Possibly, the Stroop task for inducing mental fatigue is too language and left cortical hemisphere based to reflect mental fatigue on right-hemisphere based tasks associated with the 3D-MOT. Future investigators should consider these and other bases for these findings and might test whether repeated mental fatigue worsens 3D-MOT performance.

Previous studies showed that mental fatigue impairs visual search behavior (L. de S. Fortes et al., 2022; Smith et al., 2016). Smith et al. (Smith et al., 2016) found a lower number of fixations and high fixation duration in 2 vs. 1 formation and a lower percentage of fixations in 3 vs. 2 formations when soccer athletes were mentally fatigued. Similarly, Fortes et al. (L. de S. Fortes et al., 2022) found a decrease of ~9% in the number of fixations after basketball athletes played a sport-based videogame. In both studies, the visual search behavior was measured during a decision-making task involving specific-sport scenes (i.e., soccer and basketball, respectively). Moreover, eye-tracking parameters were used to measure the ocular response to visual search. We used a laboratory task to measure the visual search based on general aspects of team sports, and we did not use a physiological measure, such as eye-tracking. These differences might partly explain why mental fatigue did not affect the 3D-MOT performance for these participants. Standardized laboratory stimuli (i.e., computerized and off-field stimuli) may not have been impacted by mental fatigue in the same way as on-field situations were. Moreover, despite our finding that the objective performance was not impaired, future investigations should include a physiological measure (i.e., electroencephalogram or eye-tracking) throughout 3D-MOT to further refine this performance measurement.

Although most 3D-MOT studies used only the speed threshold as an indicator for performance (Park et al., 2021), we also analyzed the score of the fastest trial, considering that, together, these parameters could give a broader response regarding mental fatigue. However, none of these parameters were affected by mental fatigue inducement. Somehow, the above-mentioned parameters influenced each other, since, when the speed of the spheres was fast, the participants tended to make more mistakes and the opposite occurred at low speeds. This result would have impacted the score (Holcombe & Chen, 2012; Vater et al., 2021). and it partially explains the lack of effect of mental fatigue in all parameters investigated. However, the score reflects cognitive performance on the 3D-MOT (Parsons et al., 2016; Romeas et al., 2016) and it is related to specific basketball parameters (Mangine et al., 2014). Thus, our finding that it was unaffected by mental fatigue indicates that 3D-MOT was not sensitive to mental fatigue in our young basketball players.

Increased cognitive effort can generate mental fatigue, which, in turn, impairs the performance of subsequent cognitive skills (Faro et al., 2022; Fortes et al., 2022). Our results showing that MOT ability was not negatively affected by mental fatigue after 15 sessions may suggest that MOT training may not only improve perceptual-cognitive skills, but it may also increase resistance to mental fatigue in young athletes. This becomes important because others have shown that participation in training sessions and competitions during the season causes accumulated mental fatigue that can compromise athletes' performance (Russell et al., 2022)

Limitations and Directions for Further Research

In the present experimental protocol, we consolidated the 3D-MOT measures by training the athletes over 15 sessions to stabilize the learning function and have a consistent response baseline (Faubert, 2013). This procedure may have stabilized 3D-MOT performance and eliminated the task-learning effect. However, a preliminary study has shown that prior training of athletes can reduce susceptibility to acute physical fatigue as demonstrated by unaffected 3D-MOT scores, while athletes untrained (not consolidated) on 3D-MOT did show a detrimental effect of acute physical fatigue on 3D-MOT scores (Faubert & Barthes, 2018). Perhaps the same phenomenon is observed here for mental fatigue, given that all the athletes were pre-trained (consolidated) (Faubert & Berthes, 2018).

Another factor that should be considered in the present study was the age of the players. Since our sample was ~16 years old, they were teenagers. Some evidence suggests that the effects of mental fatigue are not equal in adolescents and adults. In this sense, in a study with young soccer athletes from different categories (U-14, U-16 and U-18), Filipas et al. (2020), found worse results in technical and physical performances in older athletes after being induced by mental fatigue compared to younger athletes. Also, in our study, the athletes reported feeling mentally exhausted after 60 minutes of the Stroop task, but their 3D-MOT performance was not impacted. One explanation may be that these participants' youth was associated greater resilience in frontal lobe brain functioning due to the earlier stage of their brain development. The brain regions related to inhibitory response, such as the frontal lobe, especially the anterior cingulate cortex, develop most between the ages of 12 and 17 (Romine & Reynolds, 2005). This is a period of development of functional neural networks and patterns of activation of specific tasks that support the increase in cognitive performance (Rubia et al., 2006). Furthermore, the activation of brain regions such as the prefrontal cortex, the anterior cingulate, and the parietal cortex is greater in adults than in children/adolescents when performing the Stroop task (Adleman et al., 2002). In this way, youth provide them with resilience against mental fatigue that adults don't appreciate.

Beyond these concerns, other bases for cautious interpretation of our findings include that our sample came from only one team sport and presented a low weekly training load, which characterizes them as amateur athletes. Although the subjective response and response time (but not accuracy) on the Stroop task suggested that mental fatigue occurred, the cognitive load was not individualized, and the magnitude of the mental fatigue inducement impact might have been too low to impact 3D-MOT performance. Since some previous findings suggested that physiological markers of visual search (i.e., eye-tracking parameters) were negatively impacted by mental fatigue, future studies should include eye-tracking parameters during the 3D-MOT task. Moreover, our experimental design has laboratory predominance and its applicability in sport-field is limited.

Finally, our small sample might partially explain the lack of significant results. We cannot rule out the possibility that our sample size left us with insufficient statistical power to detect a small effect size difference between the experimental and control conditions. Additionally, generalization of results is limited from so small a sample. Future investigators would be well advised to include a larger participant sample that is more diverse in age and gender.

Conclusions

In sum, subjective (i.e., NASA-TLX) and behavioral (i.e., Stroop task response time) parameters were impaired during and after mental fatigue inducement, but 3D-MOT parameters (i.e., score and fastest velocity) were not impacted. Thus, the 3D-MOT skill was not impacted by acute mental fatigue in young athletes and should not be used as a manipulation check of this psychobiological state for this population.

Declaration of interest statement

There is no conflict of interest.

References

Adleman, N. E., Menon, V., Blasey, C. M., White, C. D., Warsofsky, I. S., Glover, G. H. & Reiss, A. L. (2002). A developmental fMRI study of the Stroop color-word task. *NeuroImage*. https://doi.org/10.1006/nimg.2001.1046

Cao, S., Geok, S. K., Roslan, S., Sun, H., Lam, S. K. & Qian, S. (2022). Mental Fatigue and Basketball Performance: A Systematic Review. *Frontiers in Psychology*, *12*(January). https://doi.org/10.3389/fpsyg.2021.819081

Dong, L., Pageaux, B., Romeas, T. & Berryman, N. (2022). The effects of fatigue on perceptual-cognitive performance among open-skill sport athletes: A scoping review. *International Review of Sport and Exercise Psychology*, 1–52. https://doi.org/10.1080/1750984X.2022.2135126

Ehmann, P., Beavan, A., Spielmann, J., Mayer, J., Altmann, S., Ruf, L., Rohrmann, S., Irmer, J. P. & Englert, C. (2022). Perceptual-cognitive performance of youth soccer players in a 360°-environment – Differences between age groups and performance levels. *Psychology of Sport and Exercise*, *59*(December 2021), 102120. https://doi.org/10.1016/j.psychsport.2021.102120

Faro, H., Fortes, L. D. S., Lima-Junior, D. D., Barbosa, B. T., Ferreira, M. E. C. & Almeida, S. S. (2022). Sport-based video game causes mental fatigue and impairs visuomotor skill in male basketball players. *International Journal of Sport and Exercise Psychology*. https://doi.org/10.1080/1612197X.2022.2109187

Faro, Heloiana, Fortes, L. de S., Lima-Júnior, D. de, Barbosa, B. T., Ferreira, M. E. C. & Almeida, S. S. (2022). Sport-based video game causes mental fatigue and impairs visuomotor skill in male basketball players. *International Journal of Sport and Exercise Psychology*, 1–15. https://doi.org/10.1080/1612197X.2022.2109187

Faubert, J. (2013a). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. *Scientific Reports*, *3*, 22–24. https://doi.org/10.1038/srep01154

Faubert, J. (2013b). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. *Scientific Reports*, *3*, 22–24. https://doi.org/10.1038/srep01154

Faubert, J. & Berthes, S. (2018). Prior Perceptual-Cognitive Training Builds Mental Resistance During Acute Physical Fatigue In Professional Rugby Athletes. *BioRxiv*, *December 2018*. https://doi.org/10.1101/505313

Faubert, J. & Sidebottom, L. (2012). Perceptual-cognitive training of athletes. *Journal of Clinical Sport Psychology*, *6*(1), 85–102. https://doi.org/10.1123/jcsp.6.1.85

Fortes, L. de S., de Lima-Júnior, D., Fiorese, L., Nascimento-Júnior, J. R. A., Mortatti, A. L. & Ferreira, M. E. C. (2020). The effect of smartphones and playing video games on decision-making in soccer players: A crossover and randomised study. *Journal of Sports Sciences*, *38*(5), 552–558. https://doi.org/10.1080/02640414.2020.1715181

Fortes, L. de S., Lima-Júnior, D. de, Barbosa, B. T., Faro, H., Ferreira, M. E. C. & Almeida, S. S. (2022). Effect of mental fatigue on decision-making skill and visual search behaviour in basketball players: an experimental and randomised study. *International Journal of Sport and Exercise Psychology*, *0*(0), 1–20. https://doi.org/10.1080/1612197x.2022.2058055

Fortes, L. S., Lima-Junior, D., Barbosa, B. T., Faro, H. K. C., Ferreira, M. E. C. & Almeida, S. S. (2022). Effect of mental fatigue on decision-making skill and visual search behaviour in basketball players: an experimental and randomised study. *International Journal of Sport and Exercise Psychology*. https://doi.org/10.1080/1612197X.2022.2058055

Hodges, N. J., Wyder-Hodge, P. A., Hetherington, S., Baker, J., Besler, Z. & Spering, M. (2021). Topical Review: Perceptual-cognitive Skills, Methods, and Skill-based Comparisons in Interceptive Sports. *Optometry and Vision Science*, *98*(7), 681–695. https://doi.org/10.1097/OPX.0000000000001727

Holcombe, A. O. & Chen, W. Y. (2012). Exhausting attentional tracking resources with a single fast-moving object. *Cognition*, *123*(2), 218–228. https://doi.org/10.1016/j.cognition.2011.10.003

Jin, P., Li, X., Ma, B., Guo, H., Zhang, Z. & Mao, L. (2020). Dynamic visual attention characteristics and their relationship to match performance in skilled basketball players. *PeerJ*, *8*, 1–16. https://doi.org/10.7717/peerj.9803

Koo, T. K. & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Liu, S., Edmunds, F. R., Burris, K. & Appelbaum, L. G. (2020). Visual and oculomotor abilities predict professional baseball batting performance. *International Journal of Performance Analysis in Sport*, *20*(4), 683–700. https://doi.org/10.1080/24748668.2020.1777819

Mangine, G. T., Hoffman, J. R., Wells, A. J., Gonzalez, A. M., Rogowski, J. P., Townsend, J. R., Jajtner, A. R., Beyer, K. S., Bohner, J. D., Pruna, G. J., Fragala, M. S. & Stout, J. R. (2014). Visual tracking speed is related to basketball-specific measures of performance in NBA players. *The Journal of Strength and Conditioning Research Conditioning*, *28*(9), 2406–2414.

Marcora, S. M., Staiano, W. & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *Journal of Applied Physiology*, *106*(3), 857–864. https://doi.org/10.1152/japplphysiol.91324.2008

Martin, K., Staiano, W., Menaspà, P., Hennessey, T., Marcora, S. M., Keegan, R., Thompson, K. G., Martin, D. T., Halson, S. & Rattray, B. (2016). Superior inhibitory control and resistance to mental fatigue in professional road cyclists. *PLoS ONE*, *11*(7), 1–15. https://doi.org/10.1371/journal.pone.0159907

Mesquita, P. H. C., Lage, G. M., Franchini, E., Romano-Silva, M. A. & Albuquerque, M. R. (2019). Bi-hemispheric anodal transcranial direct current stimulation worsens taekwondo-related performance. *Human Movement Science*, *66*, 578–586. https://doi.org/10.1016/j.humov.2019.06.003

Morgan, S. & Patterson, J. (2009). Differences in oculomotor behaviour between elite athletes from visually and non-visually oriented sports. *International Journal of Sport Psychology*, *40*(4), 489–505.

Park, S. Y., Klotzbier, T. J. & Schott, N. (2021). The effects of the combination of high-intensity interval training with 3D-multiple object tracking task on perceptual-cognitive performance: A randomized controlled intervention trial. *International Journal of Environmental Research and Public Health*, *18*(9). https://doi.org/10.3390/ijerph18094862

Parsons, B., Magill, T., Boucher, A., Zhang, M., Zogbo, K., Bérubé, S., Scheffer, O., Beauregard, M. & Faubert, J. (2016). Enhancing Cognitive Function Using Perceptual-Cognitive Training. *Clinical EEG and Neuroscience*, *47*(1), 37–47. https://doi.org/10.1177/1550059414563746

Romeas, T., Chaumillon, R., Labbé, D. & Faubert, J. (2019). Combining 3D-MOT With Sport Decision-Making for Perceptual-Cognitive Training in Virtual Reality. *Perceptual and Motor Skills*, *126*(5), 922–948. https://doi.org/10.1177/0031512519860286

Romeas, T., Guldner, A. & Faubert, J. (2016). 3D-Multiple Object Tracking training task improves passing decision-making accuracy in soccer players. *Psychology of Sport and Exercise*, *22*(June), 1–9. https://doi.org/10.1016/j.psychsport.2015.06.002

Romine, C. B. & Reynolds, C. R. (2005). A model of the development of frontal lobe functioning: Findings from a meta-analysis. In *Applied Neuropsychology*. https://doi.org/10.1207/s15324826an1204_2

Rubia, K., Smith, A. B., Woolley, J., Nosarti, C., Heyman, I., Taylor, E. & Brammer, M. (2006). Progressive increase of frontostriatal brain activation from childhood to adulthood during event-related tasks of cognitive control. *Human Brain Mapping*. https://doi.org/10.1002/hbm.20237

Russell, S., Jenkins, D. G., Halson, S. L., Juliff, L. E. & Kelly, V. G. (2022). How do elite female team sport athletes experience mental fatigue? Comparison between international competition, training and preparation camps. *European Journal of Sport Science*, *22*(6), 877–887. https://doi.org/10.1080/17461391.2021.1897165

Sirnik, M., Erčulj, F. & Rošker, J. (2022a). Research of visual attention in basketball shooting: A systematic review with meta-analysis. *International Journal of Sports Science & Coaching*. https://doi.org/10.1177/17479541221075740

Sirnik, M., Erčulj, F. & Rošker, J. (2022b). Research of visual attention in basketball shooting: A systematic review with meta-analysis. *International Journal of Sports Science & Coaching*. https://doi.org/10.1177/17479541221075740

Smith, M. R., Zeuwts, L., Lenoir, M., Hens, N., De Jong, L. M. S. & Coutts, A. J. ames. (2016). Mental fatigue impairs soccer-specific decision-making skill. *Journal of Sports Sciences*, *34*(14), 1297–1304. https://doi.org/10.1080/02640414.2016.1156241

Vaeyens, R., Lenoir, M., Williams, A. M., Mazyn, L. & Philippaerts, R. M. (2007). The effects of task constraints on visual search behavior and decision-making skill in youth soccer players. *Journal of Sport and Exercise Psychology*, *29*(2), 147–169. https://doi.org/10.1123/jsep.29.2.147

Van Cutsem, J., De Pauw, K., Vandervaeren, C., Marcora, S. M., Meeusen, R. & Roelands, B. (2019). Mental fatigue impairs visuomotor response time in badminton players and controls. *Psychology of Sport and Exercise*, *45*(February), 101579. https://doi.org/10.1016/j.psychsport.2019.101579

Van Cutsem, J., Marcora, S. M., De Pauw, K., Bailey, S. P., Meeusen, R. & Roelands, B. (2017). The Effects of Mental Fatigue on Physical Performance: A Systematic Review. *Sports Medicine*, *47*(8), 1569–1588. https://doi.org/10.1007/s40279-016-0672-0

Van Cutsem, J., Van Schuerbeek, P., Pattyn, N., Raeymaekers, H., De Mey, J., Meeusen, R. & Roelands, B. (2022). A drop in cognitive performance, whodunit? Subjective mental fatigue, brain deactivation or increased parasympathetic activity? It's complicated! *Cortex*, *155*, 30–45. https://doi.org/10.1016/j.cortex.2022.06.006

Vater, C., Gray, R. & Holcombe, A. O. (2021). A critical systematic review of the Neurotracker perceptual-cognitive training tool. *Psychonomic Bulletin and Review*, *28*(5), 1458–1483. https://doi.org/10.3758/s13423-021-01892-2

Williams, A. M., Ward, P., Bell-Walker, J. & Ford, P. R. (2012). Perceptual-cognitive expertise, practice history profiles and recall performance in soccer. *British Journal of Psychology*, *103*(3), 393–411. https://doi.org/10.1111/j.2044-8295.2011.02081.x

Williams, A. Mark & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human Movement Science*, *24*(3), 283–307. https://doi.org/10.1016/j.humov.2005.06.002

Figure 1. Study design

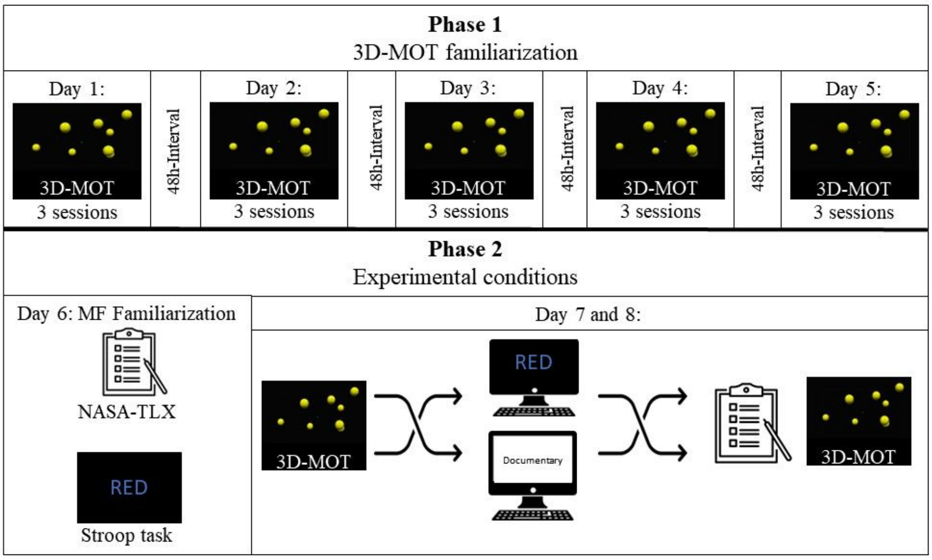
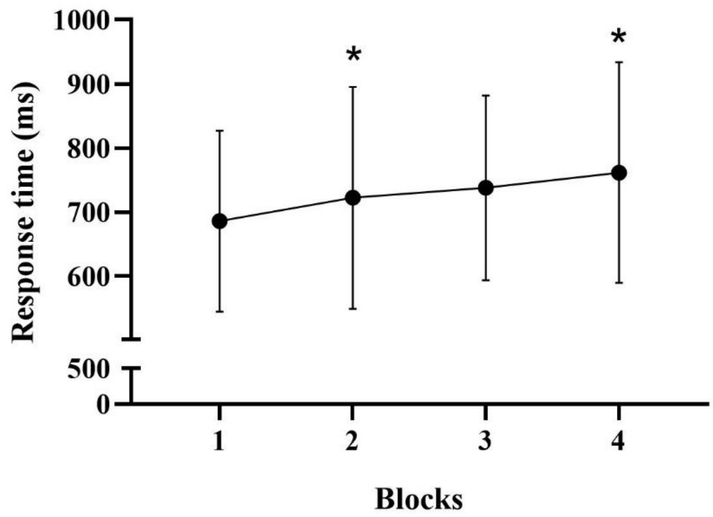


Figure 2. Response time of Stroop task during mental fatigue condition;



Note: * = significative difference to 1st block

Figure 3. 3D-MOT parameters result in pre- and post-mental fatigue

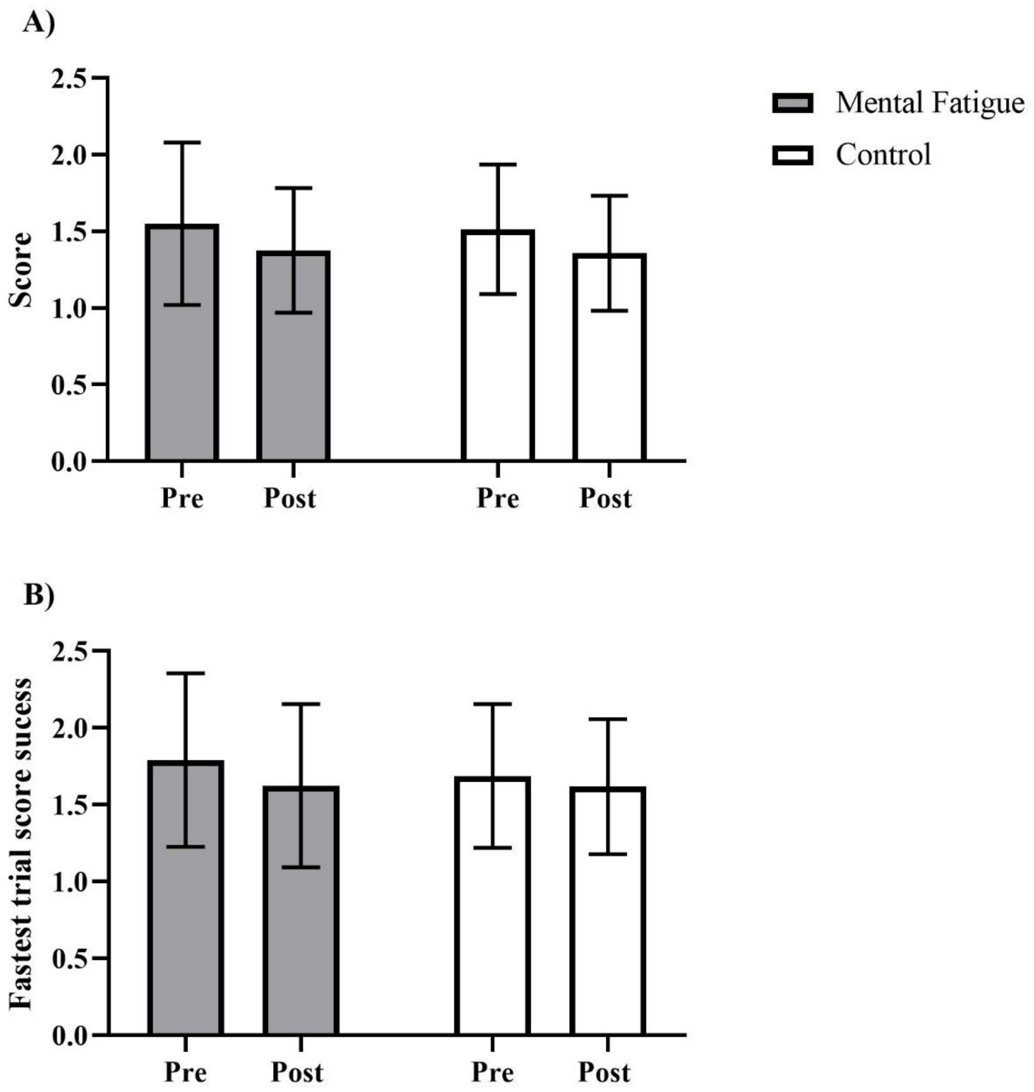


Table 1. NASA-TLX Results after Mental Fatigue Inducement and Control Conditions

	Mental Fatigue	**Control**	***p* value**
Mental demand	59 (22)	32 (24)	0.020
Temporal demand	41 (23)	29 (22)	0.049
Performance	74 (19)	79 (19)	0.194
Frustration level	37 (21)	20 (12)	0.008

Note: Scores are mean values (and standard deviations).