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

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(Article begins on next page)

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3 1 **Young Basketball Players' Multiple Object Tracking Skills Were Unaffected by**  
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5 2 **Stroop-Induced Mental Fatigue**  
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10 4 **Abstract**

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12 5 We aimed to examine the acute effect of mental fatigue on young basketball players'  
13  
14 6 three-dimensional multiple object tracking (3D-MOT) skills. Our participants were 12  
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16 7 adolescent basketball players ( $M$  age = 16.66,  $SD$  = 1.87 years;  $M$  years of practice = 2.66,  
17  
18 8  $SD$  = 1.07 years). In nine lab visits, we used visits 1 to 7 to familiarize participants with  
19  
20 9 3D-MOT, a subjective scale of mental fatigue, and a Stroop task involving mental set  
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22 10 shifting. In the last two visits, participants performed in both experimental (EXP) and  
23  
24 11 control (CON) conditions that were presented in randomized order. In the EXP condition,  
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26 12 participants performed 3D-MOT pre- and post-60 minutes of induced mental fatigue; in  
27  
28 13 the CON condition, they watched a documentary. After each condition, B participants  
29  
30 14 performed the National Aeronautics and Space Administration Task Load Index (NASA-  
31  
32 15 TLX). 3D-MOT performance measures were the "score" and "fastest trial score success."  
33  
34 16 The response time on the Stroop tasks increased throughout the mental fatigue  
35  
36 17 inducement in the experimental condition ( $p$  = 0.0037). The NASA-TLX responses were  
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38 18 higher following the EXP condition than following the CON condition for mental  
39  
40 19 demand, temporal demand, and performance (all  $ps$  < 0.05). Still, there were no  
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42 20 significant EXP versus CON differences on the 3D-MOT performance indicators.  
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51 22 **Keywords:** cognition; perceptual-cognitive skill; team sports  
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## Introduction

28 Interceptive sports, like basketball, are activities that require coordination  
29 between an object (e.g., a ball) and an athlete's body/part, involving a dynamic context  
30 and well-developed perceptual-cognitive skills (Dong et al., 2022). These skills allow the  
31 player to evaluate and integrate sensory information accompanied by previous tactical  
32 knowledge, resulting in efficient interactions with the environment (Hodges et al., 2021;  
33 A. M. Williams et al., 2012). Furthermore, visual perception is often the perceptual-  
34 cognitive skill on which most sports, including basketball, are central (Sirnik et al.,  
35 2022a). This coordination skill has been considered a main contributing factor to  
36 successful performance in team sports, including basketball (Liu et al., 2020).

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

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

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3 51 Interestingly, the speed at which multiple objects can be visually tracked is  
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5 52 correlated with specific abilities required in basketball, such as assists (i.e., actions to pass  
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7 53 the ball to the teammate who scores a basket) and steals (i.e., steals of the ball by a  
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10 54 defensive player through an interception) (Jin et al., 2020; Mangine et al., 2014). In this  
11  
12 55 way, the velocity at which athletes can perform correctly in the MOT seems to be the  
13  
14 56 most important indicator of task success. Indeed, Faubert (2013a) showed that the speed  
15  
16 57 threshold in the 3D-MOT task could differ for athletes by their competitive level. Thus,  
17  
18 58 other indicators related to velocity in the task might indicate an improvement or decrease  
19  
20 59 in the MOT performance (e.g., scores and maximum speed reached). However, the  
21  
22 60 velocity itself is not enough to entirely explain performance, but an increase in the visual  
23  
24 61 search demands, visual challenges, and the rate of interactions that high speeds create also  
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26 62 play a role (Faubert & Sidebottom, 2012). Therefore, multiple indicators should be used  
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28 63 to measure performance during the MOT task.

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33 64 Considering the importance of visual tracking skills for basketball,  
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35 65 psychobiological states of readiness or fatigue might influence this skill and lead athletes  
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37 66 to worse or better performance. Studies have shown that varying levels of players' mental  
38  
39 67 fatigue might differentially affect basketball performance (Cao et al., 2022). Mental  
40  
41 68 fatigue is a psychobiological state characterized by tiredness, lack of energy, and impaired  
42  
43 69 cognitive performance after an exposure to a task requiring extensive cognitive effort  
44  
45 70 (Marcora et al., 2009). A recent systematic review revealed that free-throws, three-point  
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47 71 shots, turnovers, and decision-making were impaired by mental fatigue (Cao et al., 2022).  
48  
49 72 Also, a recent study showed that basketball players' visual performance, as measured by  
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51 73 eye-tracking, was changed by this fatigue state with resultant impairment in some  
52  
53 74 perceptual-cognitive skills (L. de S. Fortes et al., 2022). In most past experiments, mental  
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55 75 fatigue was induced by a computerized cognitive task for at least 30 minutes (Van Cutsem  
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3 76 et al., 2017); in others, mental fatigue was induced by prolonged use of social media or  
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5 77 videogame (Faro et al., 2022; Fortes et al., 2020, 2022). However, no investigator has yet  
6  
7 78 studied the effect of mental fatigue on MOT outcomes. Yet, 3D-MOT is more accessible  
8  
9 79 and easier to implement in athletes' routines than is the more often-studied eye-tracking  
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11 80 outcome measure, and it is important to isolate the specific skills that may be affected by  
12  
13 81 mental fatigue.  
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16  
17 82 Thus, we aimed to examine the acute effect of mental fatigue by using basketball  
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19 83 players' MOT skills with the 3D-MOT assessment tool. We selected basketball players  
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21 84 for this test because of the high interceptive demands of this sport and our expectation  
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23 85 that athletes' object-tracking skills would be particularly sensitive to the effects of mental  
24  
25 86 fatigue, even in young players. Previous findings also revealed changes in visuomotor  
26  
27 87 skills for mentally fatigued basketball players (Faro et al., 2022). We hypothesized that  
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29 88 MOT skill parameters (e.g., threshold speed and score) would be impaired by exposure  
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31 89 to mental fatigue.  
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## 37 91 **Method**

### 38 92 ***Participants***

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41 93 Fourteen young male basketball players from one school team voluntarily  
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43 94 participated in this study. Since the sample of the players was limited in size, it was not  
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45 95 possible to recruit them randomly; hence we recruited a convenience sample. Two  
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47 96 athletes were excluded from the analysis because they did not complete the  
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49 97 familiarization sessions, leaving 12 athletes ( $M$  age = 16.66,  $SD$  = 1.87 years;  $M$  years of  
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51 98 practice = 2.66,  $SD$  = 1.07) whose data could be used for these analyses. These athletes  
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53 99 came from the same team that competed at state and regional levels; they trained four  
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55 100 times per week for ~1.5 hours per session. The training session involved one hour of  
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3 101 technical-tactic drills and 30 minutes of physical training. Participants were informed of  
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5 102 the study's procedures and of their rights to withdraw from the study, and they gave their  
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7 103 informed assent. Parents or legal guardians of all participants also gave their informed  
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9 104 consent. The study protocol followed the World Medical Association's Declaration of  
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11 105 Helsinki and the study received approval from Ethics Committee of the Federal  
12  
13 106 University of Paraíba with the registration number: (42205621.4.0000.5188).  
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### 108 ***Study design and Procedure***

109 This is a crossover study, with the order of experimental and control conditions  
110 randomized. The study was divided into two phases with eight visits (see Figure 1). First,  
111 participants underwent 15 familiarization sessions to achieve performance stabilization  
112 of 3D-MOT in the NeuroTracker platform (NeuroTracker, Montreal, Canada). We  
113 followed Faubert (Faubert, 2013) with this procedure, the familiarization phase was split  
114 into five non-consecutive days in which there were three sessions per day, each separated  
115 by 40 minutes. During the break between session trials, the athletes remained in a room  
116 with no access to smartphones or books or a means by which they might self-induce  
117 cognitive load. They were allowed to make conversation with each other. In the second  
118 phase, we provided one session in which we familiarized participants with the survey  
119 instrument used to acquire subjective ratings of mental fatigue (i.e., National Aeronautics  
120 and Space Administration Task Load Index; NASA-TLX) and with a Stroop task (Martin  
121 et al., 2016) to induce mental fatigue. Then, participants underwent two visits scheduled  
122 one-week apart in which they experienced either the experimental condition (EXP) or the  
123 Control condition (CON). In the EXP, participants performed the 3D-MOT and  
124 underwent mental fatigue inducement for 60 minutes (i.e., engaged in the Stroop task). In  
125 the control condition (CON), participants underwent similar procedures but, in place of

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3 126 the Stroop task mental fatigue inducement, they watched a one-hour documentary film.  
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5 127 Immediately after the experiment (i.e., post-experiment), the participants answered the  
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7 128 NASA-TLX and performed the 3D-MOT again. Participants were instructed not to use  
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9 129 caffeine, social media, physical exercise, or other cognitively or physically demanding  
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11 130 activity at least six hours before experimental conditions. Before starting the treatment  
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13 131 procedures, the participants answered a pre-trial checklist confirming that they had  
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15 132 followed these recommendations. All trials lasted about 90 minutes. It is important  
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17 133 highlight that previous studies about mental fatigue also used similar experimental design  
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19 134 (e.g., mental fatigue and control conditions)  
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26 136 \*\*\*Figure 1 here\*\*\*  
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### 30 138 ***3D Multiple Object Tracking (3D-MOT)***

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33 139 The procedures of 3D-MOT application followed previous work on MOT and  
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35 140 team sports athletes (Romeas et al., 2016). A 55-inch projection screen was used to  
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37 141 display 3D-MOT CORE version 1.16.6 mode (NeuroTracker, Montreal, Canada). The  
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39 142 participant was seated comfortably in a chair at 2.70 meters from the screen. The task  
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41 143 required the participant to follow four of eight yellow 3D spheres that moved for eight  
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43 144 seconds on the screen. That is, the animation of the MOT task was rendered and showed  
44  
45 145 depth cues in relation to the sizes of the spheres and dimensions of the cube. The spheres  
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47 146 that must be followed were highlighted for two seconds before they started to move.  
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49 147 When the objects stopped, they were numbered, and the participant was required to say  
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51 148 the numbers corresponding to the spheres highlighted at the beginning of the trial. The  
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53 149 participants spoke the numbers verbally, and the researcher clicked on the spheres with  
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55 150 the numbers judged as correct by the participant. When the answer was correct, (i.e.,  
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3 151 correctly selected all four balls) the speed of the subsequent trial increased, otherwise the  
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5 152 speed decreased. For the first attempt, the speed at which the balls moved was  
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7 153 standardized to 68 cm\*s-1.). The participants performed 20 trials in each application. The  
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9 154 "score" (i.e., represented the average speed of the last four attempts) and the "fastest trial  
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11 155 score success" (i.e., maximum speed reached during attempts) as the participant's 3D-  
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13 156 MOT performance indicators.  
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19 158 ***National Aeronautics and Space Administration Task Load Index (NASA-***  
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21 159 ***TLX)***  
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24 160 To acquire subjective ratings of mental fatigue for the extent to which we had  
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26 161 induced mental fatigue, we used the NASA-TLX. This questionnaire has six domains:  
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28 162 mental demand, physical demand, temporal demand, performance, effort, and frustration.  
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30 163 However, considering that our experiment used no physical task, we excluded the  
31  
32 164 physical demand and effort domains from this survey. Each domain had a specific related  
33  
34 165 question referring to that activity. Thus, the scale was applied only after each  
35  
36 166 experimental condition. Each question was followed by a line with 20 markers that  
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38 167 limited where the participant should make their response. The corresponding marking  
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40 168 was multiplied by five to calculate the final score. The participants were asked to mark a  
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42 169 point on the line corresponding to the state of their mental fatigue for each domain at that  
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44 170 moment. Previous studies similarly used the NASA-TLX to identify the domains affected  
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46 171 by mental fatigue (Van Cutsem et al., 2019, 2022)  
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53 173 ***Treatment***

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55 174 ***EXP - Mental Fatigue.*** The modified Stroop task (Martin et al., 2016) was used  
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57 175 to induce mental fatigue in the experimental (EXP) condition of the study. Only  
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3 176 incongruent stimuli were used. Participants were instructed to respond based on the  
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5 177 word's color and ignore its meaning. The colors yellow, blue, green, and red were used  
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7 178 and each had a corresponding motor response on the keyboard (i.e., "A", "D", "J", and  
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9  
10 179 "L", respectively). To avoid delay, participants were instructed to position both hands on  
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12 180 the keyboard. The letters on the keyboard were colored to match the corresponding letter  
13  
14 181 color, as shown in Figure 2. The task was administered in four blocks of 15 minutes each,  
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16 182 for a total duration of 60 minutes. Participants were instructed to respond as quickly and  
17  
18 183 accurately as possible. The task was created and administered using the PsychoPy  
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20 184 software (version 2021.2.3, GNU General Public License) and presented on a 17-inch  
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22 185 screen in a silent, temperature-controlled room with low luminosity, and overseen by the  
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24 186 lead researcher.  
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30 188 **Documentary.** In the control condition (CON), participants watched an  
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32 189 emotionally neutral documentary (Science Mysteries - A Journey to the Center of the  
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34 190 Earth, audio in Portuguese, without subtitles) on a 17" inch screen, in a temperature-  
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36 191 controlled at 16°-18°C and with low luminosity, only with the presence of one researcher.  
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### 193 **Statistical Analysis**

194 Data normality was tested by Shapiro-Wilk and the homogeneity of variances was  
195 tested by Levene test. A 2-way mixed effects, average of measurements, and consistency  
196 agreement Intraclass Coefficient Correlated (ICC) and 95% interval of confidence  
197 (95%IC) were calculated for each variable, using the data from the three last trials (i.e.,  
198 day 5) of phase 1. The qualitative ICC classification was >0.90 "excellent", 0.75-0.90  
199 "good," 0.50-0.75 "moderate", and <0.50 "poor" (Koo & Li, 2016). The difference in the  
200 response time of Stroop task blocks was tested using the Friedman ANOVA by ranks test

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3 201 since the data for this variable did not present a normal distribution. The NASA-TLX  
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5 202 response was compared with Wilcoxon test. The remaining variables were tested using  
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7 203 repeated measures ANOVA two-way (Time x Conditions) for analyzing main effects  
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9 204 (Condition, Time) and any interaction effect of Condition X Time on the two times for  
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11 205 3D-MOT skills. If a significant difference was identified, the Bonferroni post hoc  
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13 206 procedure was used for pairwise comparisons. We calculated partial eta squared ( $\eta^2$ ) to  
14  
15 207 measure the effect size (ES) and interpreted effect sizes as small: 0.01; moderate: 0.09;  
16  
17 208 large: 0.25, as suggested by Mesquita et al. (Mesquita et al., 2019). Statistical procedures  
18  
19 209 were performed using the Statistical Package for the Social Sciences software (SPSS,  
20  
21 210 version 20.0; IBM Corp., Armonk, NY, USA). We set statistical significance at  $p < 0.05$ .  
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### Results

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30 213 *NASA-TLX*. Table 1 shows the participants' responses on the NASA-TLX domains for  
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32 214 each experimental condition. Except for frustration, all domains of NASA-TLX were  
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34 215 significantly different between conditions. Participants reported the mental demand to be  
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36 216 32% greater in the mental fatigue condition than in the control condition.  
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\*\*\*Table 1 here\*\*\*

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47 220 The response time on the Stroop task in the mental fatigue condition significantly  
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49 221 increased over time ( $p=0.0037$ ;  $F=13.300$ ;  $\eta^2=0.337$ ). These differences occurred  
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51 222 between block 1 vs block 3 ( $p=0.021$ ;  $F=12.000$ ;  $\eta^2=0.406$ ) and between block 1 vs  
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53 223 block 4 ( $p=0.004$ ;  $F=8.333$ ;  $\eta^2=0.500$ ). However, there was only a tendency toward a  
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224 significant difference in Stroop accuracy over time ( $p=0.053$ ;  $F= 2.830$ ;  $\eta_p^2= 0.205$ )  
225 (Figure 2).

226

227 \*\*\*Figure 2 here\*\*\*

228

### 229 **3D-MOT.**

230 The ICCs were “good” for Score on the 3D-MOT ( $ICC=0.806$ ;  $95\%IC=0.487-$   
231  $0.939$ ;  $p=0.001$ ) and Fastest on the 3D-MOT ( $ICC=0.765$ ;  $95\%IC=378-0.926$ ;  $p=0.002$ ),  
232 indicating acceptable reliability on these measures. The 3D-MOT variable remained  
233 unaltered after both conditions (see Figure 3).

234 While there was a significant main effect of Time on the 3D-MOT Score ( $F_{(1,11)} =$   
235  $7.084$ ,  $p = 0.027$ ,  $\eta_p^2 = 0.392$ ), follow-up analyses did not show any separate Time effect  
236 in either the EXP condition ( $F_{(1,11)} = 3.122$ ;  $p = 0.105$ ,  $\eta_p^2 = 0.221$ ) or the CON condition  
237 ( $F_{(1,11)} = 2.511$ ,  $p = 0.141$ ,  $\eta_p^2 = 0.186$ ); and there was no significant Time x Condition  
238 interaction effect ( $F_{(1,11)} = 0.014$ ;  $p = 0.097$ ,  $\eta_p^2 = 0.001$ ). Similarly, there was no Condition  
239 main effect for 3D-MOT Score ( $F_{(1,11)} = 0.110$ ;  $p = 0.747$ ;  $\eta_p^2 = 0.010$ ).

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

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\*\*\*Figure 3 here\*\*\*

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### Discussion

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10 249 We aimed to assess the potential effect of mental fatigue on basketball players'  
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12 250 MOT performance. The response time on Stroop tasks increased throughout the mental  
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14 251 fatigue experimental condition, and the participants' subjective feelings of mental  
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16 252 demand (as measured by the NASA-TLX) were higher when they were in the mental  
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18 253 fatigue condition compared to the control condition. Still, their performance across these  
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20 254 two EXP and CON conditions, as indicated by the 3D-MOT, were not significantly  
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22 255 different; and this is in contradiction to our initial hypothesis.

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26 256 Previous studies have shown that 3D-MOT was able to distinguish visual search  
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28 257 learning among professional, amateur-elite, and non-athletes (Faubert, 2013b) and that  
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30 258 engagement in it was associated with improved passing decision-making accuracy in  
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32 259 soccer players (Romeas et al., 2016). Since previous studies showed that the outcomes of  
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34 260 the 3D-MOT measures (i.e., visual search behavior) were impaired by mental fatigue (L.  
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36 261 de S. Fortes et al., 2022; Smith et al., 2016), we expected but did not find, a decline in  
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38 262 3D-MOT performance following the cognitive effort our participants experienced on the  
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40 263 Stroop task. Considering the original aim for which this tool was created (i.e., training the  
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42 264 visual search behavior), maybe a transitive state like mental fatigue did not affect the 3D-  
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44 265 MOT performance. Possibly, the Stroop task for inducing mental fatigue is too language  
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46 266 and left cortical hemisphere based to reflect mental fatigue on right-hemisphere based  
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48 267 tasks associated with the 3D-MOT. Future investigators should consider these and other  
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50 268 bases for these findings and might test whether repeated mental fatigue worsens 3D-  
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52 269 MOT performance.

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3 271 Previous studies showed that mental fatigue impairs visual search behavior (L. de  
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5 272 S. Fortes et al., 2022; Smith et al., 2016). Smith et al. (Smith et al., 2016) found a lower  
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7 273 number of fixations and high fixation duration in 2 vs. 1 formation and a lower percentage  
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9 274 of fixations in 3 vs. 2 formations when soccer athletes were mentally fatigued. Similarly,  
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11 275 Fortes et al. (L. de S. Fortes et al., 2022) found a decrease of ~9% in the number of  
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13 276 fixations after basketball athletes played a sport-based videogame. In both studies, the  
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15 277 visual search behavior was measured during a decision-making task involving specific-  
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17 278 sport scenes (i.e., soccer and basketball, respectively). Moreover, eye-tracking parameters  
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19 279 were used to measure the ocular response to visual search. We used a laboratory task to  
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21 280 measure the visual search based on general aspects of team sports, and we did not use a  
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23 281 physiological measure, such as eye-tracking. These differences might partly explain why  
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25 282 mental fatigue did not affect the 3D-MOT performance for these participants.  
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27 283 Standardized laboratory stimuli (i.e., computerized and off-field stimuli) may not have  
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29 284 been impacted by mental fatigue in the same way as on-field situations were. Moreover,  
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31 285 despite our finding that the objective performance was not impaired, future investigations  
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33 286 should include a physiological measure (i.e., electroencephalogram or eye-tracking)  
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35 287 throughout 3D-MOT to further refine this performance measurement.  
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42 288 Although most 3D-MOT studies used only the speed threshold as an indicator for  
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44 289 performance (Park et al., 2021), we also analyzed the score of the fastest trial, considering  
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46 290 that, together, these parameters could give a broader response regarding mental fatigue.  
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48 291 However, none of these parameters were affected by mental fatigue inducement.  
49  
50 292 Somehow, the above-mentioned parameters influenced each other, since, when the speed  
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52 293 of the spheres was fast, the participants tended to make more mistakes and the opposite  
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54 294 occurred at low speeds. This result would have impacted the score (Holcombe & Chen,  
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56 295 2012; Vater et al., 2021). and it partially explains the lack of effect of mental fatigue in  
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3 296 all parameters investigated. However, the score reflects cognitive performance on the 3D-  
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5 297 MOT (Parsons et al., 2016; Romeas et al., 2016) and it is related to specific basketball  
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7 298 parameters (Mangine et al., 2014). Thus, our finding that it was unaffected by mental  
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9 299 fatigue indicates that 3D-MOT was not sensitive to mental fatigue in our young basketball  
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12 300 players.

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14 301 Increased cognitive effort can generate mental fatigue, which, in turn, impairs the  
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16 302 performance of subsequent cognitive skills (Faro et al., 2022; Fortes et al., 2022). Our  
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18 303 results showing that MOT ability was not negatively affected by mental fatigue after 15  
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20 304 sessions may suggest that MOT training may not only improve perceptual-cognitive  
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22 305 skills, but it may also increase resistance to mental fatigue in young athletes. This  
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24 306 becomes important because others have shown that participation in training sessions and  
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26 307 competitions during the season causes accumulated mental fatigue that can compromise  
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28 308 athletes' performance (Russell et al., 2022)

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### 34 35 310 ***Limitations and Directions for Further Research***

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37 311 In the present experimental protocol, we consolidated the 3D-MOT measures by  
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39 312 training the athletes over 15 sessions to stabilize the learning function and have a  
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41 313 consistent response baseline (Faubert, 2013). This procedure may have stabilized 3D-  
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43 314 MOT performance and eliminated the task-learning effect. However, a preliminary study  
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45 315 has shown that prior training of athletes can reduce susceptibility to acute physical fatigue  
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47 316 as demonstrated by unaffected 3D-MOT scores, while athletes untrained (not  
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49 317 consolidated) on 3D-MOT did show a detrimental effect of acute physical fatigue on 3D-  
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51 318 MOT scores (Faubert & Barthes, 2018). Perhaps the same phenomenon is observed here  
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53 319 for mental fatigue, given that all the athletes were pre-trained (consolidated) (Faubert &  
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55 320 Berthes, 2018).

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3 321 Another factor that should be considered in the present study was the age of the  
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5 322 players. Since our sample was ~16 years old, they were teenagers. Some evidence  
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7 323 suggests that the effects of mental fatigue are not equal in adolescents and adults. In this  
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9 324 sense, in a study with young soccer athletes from different categories (U-14, U-16 and U-  
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11 325 18), Filipas et al. (2020), found worse results in technical and physical performances in  
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13 326 older athletes after being induced by mental fatigue compared to younger athletes. Also,  
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15 327 in our study, the athletes reported feeling mentally exhausted after 60 minutes of the  
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17 328 Stroop task, but their 3D-MOT performance was not impacted. One explanation may be  
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19 329 that these participants' youth was associated greater resilience in frontal lobe brain  
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21 330 functioning due to the earlier stage of their brain development. The brain regions related  
22  
23 331 to inhibitory response, such as the frontal lobe, especially the anterior cingulate cortex,  
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25 332 develop most between the ages of 12 and 17 (Romine & Reynolds, 2005). This is a period  
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27 333 of development of functional neural networks and patterns of activation of specific tasks  
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29 334 that support the increase in cognitive performance (Rubia et al., 2006). Furthermore, the  
30  
31 335 activation of brain regions such as the prefrontal cortex, the anterior cingulate, and the  
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33 336 parietal cortex is greater in adults than in children/adolescents when performing the  
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35 337 Stroop task (Adleman et al., 2002). In this way, youth provide them with resilience against  
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37 338 mental fatigue that adults don't appreciate.

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39 339 Beyond these concerns, other bases for cautious interpretation of our findings  
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41 340 include that our sample came from only one team sport and presented a low weekly  
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43 341 training load, which characterizes them as amateur athletes. Although the subjective  
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45 342 response and response time (but not accuracy) on the Stroop task suggested that mental  
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47 343 fatigue occurred, the cognitive load was not individualized, and the magnitude of the  
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49 344 mental fatigue inducement impact might have been too low to impact 3D-MOT  
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51 345 performance. Since some previous findings suggested that physiological markers of  
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3 346 visual search (i.e., eye-tracking parameters) were negatively impacted by mental fatigue,  
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5 347 future studies should include eye-tracking parameters during the 3D-MOT task.  
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7 348 Moreover, our experimental design has laboratory predominance and its applicability in  
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9 349 sport-field is limited.

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12 350 Finally, our small sample might partially explain the lack of significant results.  
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14 351 We cannot rule out the possibility that our sample size left us with insufficient statistical  
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16 352 power to detect a small effect size difference between the experimental and control  
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18 353 conditions. Additionally, generalization of results is limited from so small a sample.  
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21 354 Future investigators would be well advised to include a larger participant sample that is  
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23 355 more diverse in age and gender.

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## 27 28 357 **Conclusions**

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30 358 In sum, subjective (i.e., NASA-TLX) and behavioral (i.e., Stroop task response  
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32 359 time) parameters were impaired during and after mental fatigue inducement, but 3D-MOT  
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34 360 parameters (i.e., score and fastest velocity) were not impacted. Thus, the 3D-MOT skill  
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36 361 was not impacted by acute mental fatigue in young athletes and should not be used as a  
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38 362 manipulation check of this psychobiological state for this population.

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## 48 49 366 **Declaration of interest statement**

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51 367 There is no conflict of interest.

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## 55 56 369 **References**

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Figure 1. Study design

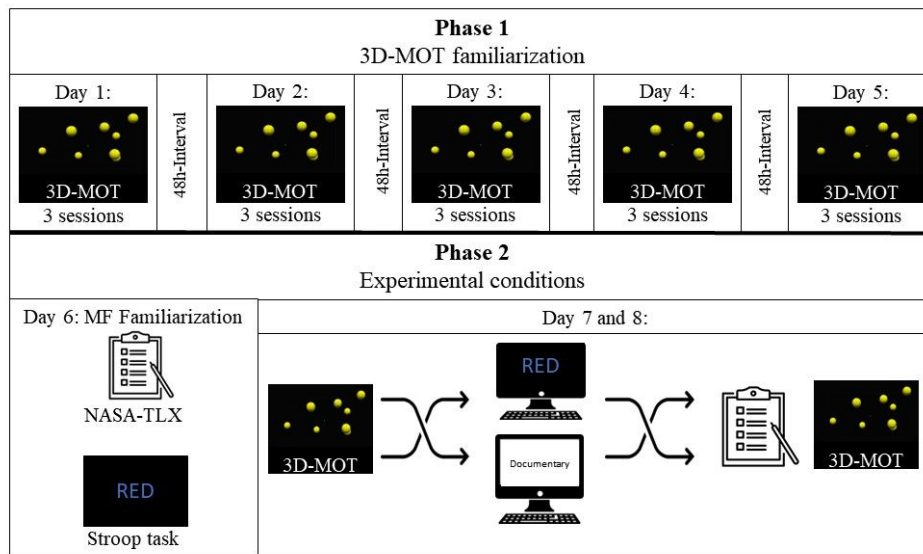
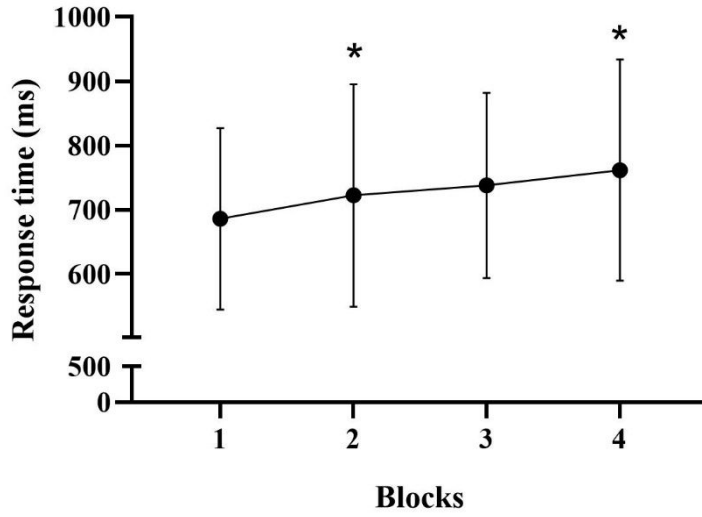
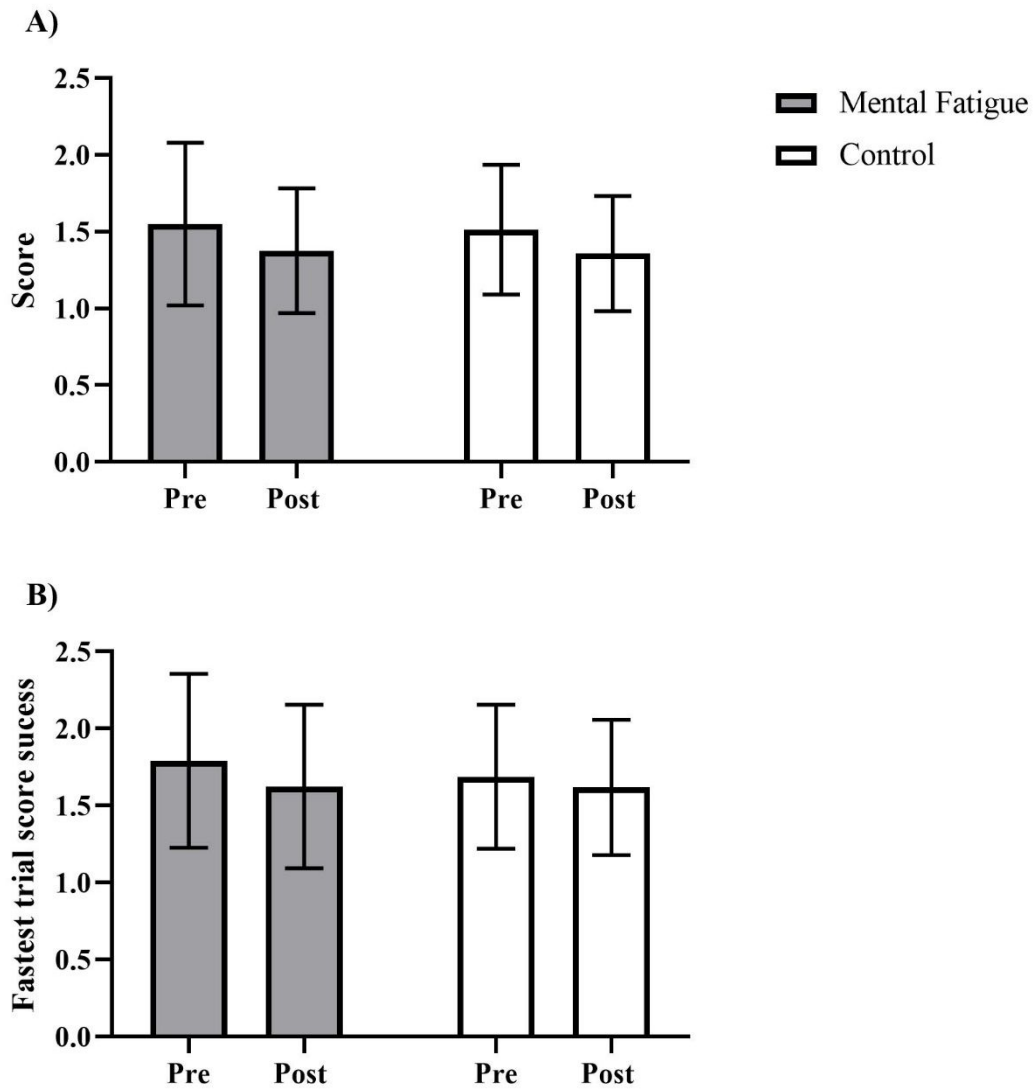


Figure 2. Response time of Stroop task during mental fatigue condition;



Note: \* = significant difference to 1<sup>st</sup> 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

	<b>Mental Fatigue</b>	<b>Control</b>	<b><i>p</i> value</b>
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).