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Smartphone Use Among High Level Swimmers Is Associated With Mental Fatigue and Slower 100- and 200- but Not 50-Meter Freestyle Racing

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## Perceptual and Motor Skills

### Smartphone Use Among High Level Swimmers Is Associated with Mental Fatigue and Slower 100- and 200- but not 50-meter Freestyle Racing

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Keywords:	Cognition < Learning & Memory, Psychological fatigue < Ergonomics < Motor Skills & Ergonomics, Media, Factors in sport performance < Sport psychology < Exercise & Sport, Sport psychology < Exercise & Sport
Abstract:	<p>Discovering any performance degradation effect of racing swimmers' use of social media smartphone apps might lead to new training and race preparation protocols, including pre-meet smartphone avoidance. This study's objective was to analyze the performance effects of using smartphone social media apps on the 50, 100, and 200-m freestyle among 25 high-level swimmers. Each participant performed the three race distances in two conditions: with smartphone app exposure (50-MF, 100-MF, and 200-MF) and without (50-CON, 100-CON, and 200-CON). We randomized the order of these two conditions across participants. While smartphone app use was not associated with statistically significant performance differences on the shortest race (50CON versus 50MF), a repeated measures ANOVA showed a significant condition x time interaction for the swimmers' 100-m freestyle performance (<math>p = 0.01</math>), with a significantly slower performance following smartphone app use evident in the last half of this race (<math>p = 0.02</math>) but not in the first half (<math>p = 0.41</math>). We also found a condition x time interaction in the same direction (slower for swimmers who used the smartphone app) for the 200-m freestyle performance (<math>p = 0.01</math>), with the slower performance occurring in the second (<math>p = 0.01</math>) but not the first (<math>p = 0.91</math>), third (<math>p = 0.07</math>) or fourth (<math>p = 0.06</math>) quarters of this race. Thus, prolonged smartphone social media app use was associated with reduced performance from elite swimmers on the 100- and 200- but not the 50-m freestyle.</p>

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Manuscripts

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## Abstract

Discovering any performance degradation effect of racing swimmers' use of social media smartphone apps might lead to new training and race preparation protocols, including pre-meet smartphone avoidance. This study's objective was to analyze the performance effects of using smartphone social media apps on the 50, 100, and 200-m freestyle among 25 high-level swimmers. Each participant performed the three race distances in two conditions: with smartphone app exposure (50-MF, 100-MF, and 200-MF) and without (50-CON, 100-CON, and 200-CON). We randomized the order of these two conditions across participants. While smartphone app use was not associated with statistically significant performance differences on the shortest race (50CON versus 50MF), a repeated measures ANOVA showed a significant condition x time interaction for the swimmers' 100-m freestyle performance ( $p = 0.01$ ), with a significantly slower performance following smartphone app use evident in the last half of this race ( $p = 0.02$ ) but not in the first half ( $p = 0.41$ ). We also found a condition x time interaction in the same direction (slower for swimmers who used the smartphone app) for the 200-m freestyle performance ( $p = 0.01$ ), with the slower performance occurring in the second ( $p = 0.01$ ) but not the first ( $p = 0.91$ ), third ( $p = 0.07$ ) or fourth ( $p = 0.06$ ) quarters of this race. Thus, prolonged smartphone social media app use was associated with reduced performance from elite swimmers on the 100- and 200- but not the 50-m freestyle.

*Keywords:* cognition, fatigue, media, performance, psychology.

## 23 Introduction

24 Swimming is an individual sport performed in aquatic environments (i.e., 50-meter  
25 swimming pool) (Kalva-Filho et al., 2015). The competitive swimming program typically  
26 includes race variants of distance (50 to 1.500-m) and style (freestyle, butterfly, backstroke,  
27 breaststroke, and medley; Barroso, Salgueiro, Carmo, & Nakamura, 2015). Performance in  
28 the 50, 100, and 200-m freestyle races depend on several factors, such as the athlete's  
29 physical, physiological, technical, and tactical characteristics (Fortes et al., 2017; Kalva-Filho  
30 et al., 2015). For example, in the 100 and 200-m freestyle world championship, an athlete's  
31 pacing strategy (e.g., positive, negative, "J-shape," or parabolic) may determine the outcome  
32 (McGibon, Pyne, Shepard, & Thompson, 2018).

33 According to Bangsbo (2015), success in this sport depends on a well-developed set  
34 of physical (e.g., anaerobic capacity, anaerobic, and aerobic power), cognitive (e.g., attention,  
35 inhibitory control, cognitive flexibility, coping, and emotional control), technical (e.g.,  
36 underwater ripple and turn), and tactical (e.g., pace strategy) abilities. In sports like cycling  
37 and swimming, executive functions (e.g., attention and inhibitory control) also play an  
38 important role in performance. Block reaction time requires well-trained attention, and pace  
39 strategy requires well developed inhibitory control (Franco-Alvarenga et al., 2019).

40 Inhibitory control is a core executive function related for successful task performance  
41 (Diamond, 2015). A reduction in attention and inhibitory control would be expected to impair  
42 performance, especially in races that require sustained effort (e.g., 100 and 200-m freestyle).  
43 A mentally fatigued athlete might experience reduced attention and inhibition control (Fortes  
44 et al., 2019; Franco-Alvarenga et al., 2019).

45 Mental fatigue is a psychobiological state defined by feelings of tiredness and a lack  
46 of energy, and it is induced by prolonged periods of high demands on cognitive activity  
47 (Marcora, Staiano, & Manning et al., 2009; Smith et al., 2018). Neural pathways such as the

## MENTAL FATIGUE AND SWIMMING

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3 48 anterior cingulate cortex, dorsolateral prefrontal cortex, pre-supplementary motor area,  
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5 49 inferior frontal gyrus, and medial superior parietal cortex are activated during executive  
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7 50 function cognitive tasks of this kind (McMorris, Barwood, Hale, Dicks, & Corbett, 2018).  
8  
9 51 Those tasks require an inhibition response and sustained vigilance (e.g., the Stroop task,  
10  
11 52 reading, driving, playing video game, and smartphone use) and might be expected to induce  
12  
13 53 mental fatigue (Fortes et al., 2019; Martin, Meeusen, Thompson, Keegan, & Rattray, 2018;  
14  
15 54 Smith et al., 2018).

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18  
19 55 Other research findings have suggested that using smartphones for a prolonged period  
20  
21 56 might cause mental fatigue in athletes (Russel, Jenkins, Rynne, Halson, & Kelly, 2019a).  
22  
23 57 Recently, Fortes et al. (2019) showed that 30-min of social media apps on smartphones  
24  
25 58 caused mental fatigue in soccer athletes. Although swimmers fatigue from smartphone use  
26  
27 59 has not been investigated in the scientific literature, it is common for swimming athletes to  
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29 60 use social network apps (e.g., Facebook, WhatsApp, and Instagram), including use just  
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31 61 before official championship races. Since extended use of social media apps may induce  
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33 62 mental fatigue (Fortes et al., 2019), we assumed that 50, 100, and 200-m freestyle  
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35 63 performances might be negatively impacted by this activity, and we sought to confirm this  
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37 64 hypothesis through an experimental study.

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42 65 Mental fatigue may impair physical performance on tasks with a duration greater than  
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44 66 30-seconds, as an integrative literature review has found (Martin et al., 2018). Another  
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46 67 systematic literature review reported a detrimental effect of mental fatigue on athletes'  
47  
48 68 physical performance (Cutsem et al., 2017). However, to the best of our knowledge, only one  
49  
50 69 study has analyzed the effects of mental fatigue on swimming performance (Penna et al.,  
51  
52 70 2018). The protocol for inducing mental fatigue in this past study was a Stroop task (Graf,  
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54 71 Uttl, & Tuokko, 1995), which lacked ecological validity in that athletes in a real world  
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56 72 competition do not engage in this task. A better research design might use an ecologically  
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3 73 valid task to analyze the effects of smartphone social media app use on sports performance  
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5 74 (i.e., swimming). From a practical standpoint, discovering the effects of social media  
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7 75 exposure through smartphones on athletes' subsequent performance on the 50-, 100-, and  
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9 76 200-m freestyle race might suggest new pre-competition protocols, perhaps including  
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11 77 avoidance of smartphone use before races. We analyzed the effect of international-level  
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13 78 swimmers' use of social media smartphone apps on their 50-, 100-, and 200-m freestyle  
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15 79 performances. We hypothesized that 30-minutes of exposure time to smartphone applications  
16  
17 80 both sexes of these swimmers would be associated with slower swim times on 50, 100, and  
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19 81 200-m freestyle races among  
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## 26 83 **Method**

### 28 84 *Participants*

30 85 We conducted an a priori calculation to estimate our required sample size, using the  
31  
32 86 equation  $n = 8e^2/d^2$  where  $n$ ,  $e$ , and  $d$  denote the required sample size, coefficient of  
33  
34 87 variation, and magnitude of the treatment, respectively. We assumed a coefficient of  
35  
36 88 variation of 1.1 % for the 100-m freestyle performed by international swimmers (McGibson  
37  
38 89 et al., 2018) and a conservative  $d$  of 1.0 %, and this calculation resulted in an estimated  
39  
40 90 requirement for ~ 15 participants.  
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44 91 Considering possible participant attrition, we recruited 25 international-level swimmers  
45  
46 92 ( $M$  age = 20.4 years,  $SD$  = 2.06;  $M$  height = 1.81 meters,  $SD$  = 0.07;  $M$  weight = 72.00 kg,  $SD$   
47  
48 93 = 9) from two swim clubs in Brazil. There were 14 men (according to International Points  
49  
50 94 Score of Fédération Internationale de Natation - FINA:  $M$  = 851.59,  $SD$  = 19.14 points for  
51  
52 95 the 50-m freestyle;  $M$  = 856.68,  $SD$  = 21.90 points for the 100-m freestyle; and  $M$  = 847.46,  
53  
54 96  $SD$  = 24.31 points for the 200-m freestyle) and 11 women (FINA Points Score:  $M$  = 893.25,  
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56 97  $SD$  = 20.90 points for the 50-m freestyle;  $M$  = 885.42,  $SD$  = 17.63 points for the 100-m  
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## MENTAL FATIGUE AND SWIMMING

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3 98 freestyle; and  $M = 866.04$ ,  $SD = 23.87$  points for the 200-m freestyle. Participants had trained  
4  
5 99 an average of 5.8 ( $SD = 0.5$ ) sessions/week for an average of 42.5 km ( $SD = 6.2$ ) swum per  
6  
7  
8 100 week, and they had  $\sim 8.4$  years experience swimming in international women present  
9  
10 101 different responses to stress and to muscle fatigue, Lopes et al. (2020) showed no sex  
11  
12 102 differences in the magnitude of decrements in aerobic performance among (e.g., energy  
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14 103 drink) or alcoholic beverages and to avoid intense exercise for 48 hours preceding their  
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17 104 swimming sessions. They were also instructed to avoid consumption of coffee and national  
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19 105 tournaments. Although Pageaux and Lepers (2018) indicated that men and mentally fatigued  
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21 106 professional runners.

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24 107 All participants were non-smokers, and all were free from cardiovascular, visual,  
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26 108 auditory, and cognitive disorders. They were instructed to avoid consumption of stimulants  
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28 109 for three hours before swimming events. We explained all experimental procedures, risks,  
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31 110 and benefits of the study; and we then obtained written consent from all participants prior to  
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33 111 their engagement in further study procedures. All study procedures were approved by a local  
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35 112 Ethics Committee and performed according to the Declaration of Helsinki.

113

**114 *Experimental design and procedure***

115 This study was a randomized, crossover investigation in which all participants  
116 performed these swimming events under six experimental conditions, each separated by a  
117 one-week washout interval. Each participant underwent three baseline visits and then swam  
118 under the six experimental conditions.

119

**120 *Baseline visits***

121 During the three baseline visits, we collected data for heart rate variability (HRV)  
122 reproducibility, the countermovement jump (CMJ) task, a Stroop task, and a participant self-

## MENTAL FATIGUE AND SWIMMING

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3 123 report on the Mental Fatigue Visual Analogue Scale (VAS) following 50, 100, and 200-m  
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5 124 freestyle swims. Next, we randomized the order of the six experimental conditions for each  
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7 125 participant using a random number table generator ([www.randomizer.org](http://www.randomizer.org)). The six  
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9 126 conditions were to swim each of the three swim distances with a prior mental fatigue  
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11 127 inducement (i.e., 50-MF, 100-MF, and 200-MF) and without a prior mental fatigue  
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13 128 inducement (i.e., 50-CON, 100-CON, and 200-CON). A one-week washout period separated  
14  
15 129 each of these swims (see Figure 1). As noted above, the participants maintained their training  
16  
17 130 routines during the washout period. The participants abstained from any physical exercise,  
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19 131 alcohol ingestion 48-h before all experimental sessions, and they abstained from caffeine for  
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21 132 at least three hours before all experimental sessions.  
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28 134 ***Experimental sessions***

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30 135 At each experimental session, we used the Stroop task to assess, rather than induce  
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32 136 mental fatigue. Assessments occurred both before and after either smartphone use (the mental  
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34 137 fatigue inducement) or watching a documentary TV show about the Olympic Games (a  
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36 138 control or non-mental fatigue experience). We recommended that the athletes ingest fluid ad  
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38 139 libidum up to two hours before each experimental session. Smartphone use two hours before  
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40 140 each experimental session was forbidden. The participants warmed-up for five minutes in a  
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42 141 swimming pool. Next, in consideration of the post-activation potential phenomenon  
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44 142 identified by Wilson et al. (2013), we gave participants another five minute warm-up interval  
45  
46 143 before beginning the simulated race (50, 100, or 200-m freestyle). Finally, the athletes swam  
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48 144 the simulated race (i.e, the 50, 100 or 200-m freestyle), adopting the official rules of the  
49  
50 145 sport. During the simulated swimming race (50, 100 or 200-m freestyle), a researcher who  
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52 146 was blind to the participant's experimental treatment condition, provided participants  
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## MENTAL FATIGUE AND SWIMMING

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3 147 continuous verbal encouragement. We measured CMJ and HRV before and ~30 minutes  
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5 148 after each experimental session.  
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10 150 **\*\*\*Figure 1 insert here\*\*\***  
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15 152 ***Control and mental fatigue protocols***

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17 153 In the non-mental fatigue or control conditions (i.e., the 50-CON, 100-CON, and 200-  
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19 154 CON conditions), participants watched 30 minutes of coaching videos about Olympic Games  
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21 155 on an 84-inch screen (smartphone free room). Studies related to mental fatigue and human  
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23 156 performance have long used these emotionally neutral 30-minute documentaries in control  
24  
25 157 conditions (Marcora et al., 2009; Moreira et al., 2018) because neither cognitive performance  
26  
27 158 (Fortes et al., 2019; Lopes et al., 2020) nor underlying brain mechanisms of mental fatigue  
28  
29 159 are altered (Franco-Alvarenga et al., 2019).  
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32  
33 160 We used social media app use on smartphones to induce mental fatigue in the  
34  
35 161 experimental conditions (i.e., the 50-MF, 100-MF, and 200-MF conditions), Participants used  
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37 162 social media apps (e.g., WhatsApp, Facebook, and Instagram) on smartphones for 30 minutes  
38  
39 163 prior to these races. We supervised the smartphone use to ensure the athletes only used social  
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41 164 media apps.  
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44 165 All participants (i.e., participants from both the experimental and control groups)  
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47 166 remained in the same room together while either using their smartphone or watching the  
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49 167 video. The participants were prohibited from speaking amongst themselves.  
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54 169 ***Measures***

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56 170 *50, 100, and 200-m freestyle swims* During the participants' simulated swimming  
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58 171 competitions, we measured their performance using Electronic boards (Daktronics®, Brazil).  
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## MENTAL FATIGUE AND SWIMMING

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3 172 We divided participants into sets of four, according to their prior performance and sex (male  
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5 173 or female). Participants remained in these same sets of four through all experimental  
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8 174 conditions. During their five-minute warm-ups, participants performed swimming sprints of  
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10 175 10 meters each minute. Next, they engaged in five-minute rest intervals before the simulated  
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12 176 race. We established this rest interval because of the potential post-activation phenomenon  
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14 177 (Wilson et al., 2013). All athletes were familiar with and needed no instructions for the 50,  
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16 178 100, and 200-m freestyle simulated races. We measured their race time in seconds, and we  
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18 179 gathered times for the completion of each 50-m segment of the longer (100 and 200-m) races  
19  
20 180 in order to determine any differences in their pacing through the races.  
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26 182 *Countermovement jump (CMJ)*. We used an electronic contact jump mat (Hidrofit®,  
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28 183 Jump System, Belo Horizonte, Brazil) to analyze the CMJ height for each participant. Each  
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30 184 participant performed three attempts with 30 second intervals between trials. We analyzed  
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32 185 and the best attempt over these three trials. Participants performed the CMJ with their hands  
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34 186 on their waists and no restrictions on the knee angle during the eccentric phase of the jump.  
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36 187 Also, the participants were instructed to maintain their legs in a straight position during the  
37  
38 188 flight phase and land at the take-off point. All participants were familiar with the test before  
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40 189 the beginning of the investigation. In the present study, the participants' intraclass correlation  
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42 190 coefficient was 0.99 (CI<sub>95%</sub> = 0.98 to 0.99) for the CMJ, indicating good test reliability.  
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49 192 *Heart rate variability (HRV)*. All evaluations were performed under the same  
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51 193 conditions. Participants remained in the sitting position for 10 minutes before starting the  
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53 194 resting HRV (Task Force, 1996). The R-R intervals (i.e., the distance between each  
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55 195 heartbeat) were obtained using a portable heart rate telemetry tape with Bluetooth (Polar®  
56  
57 196 H10, Kempele, Finland) in a sampling of 1,000 Hz and using a smartphone app (Elite HRV,  
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3 197 Perrota, Jeklin, Hives, Meanwell, & Warburton, 2017) uninterruptedly for five minutes (Task  
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5 198 Force, 1996) in a room with a temperature of 24°C. We analyzed the following variables: the  
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7  
8 199 standard deviation of all NN intervals (SDNN), the consecutive percentage of R-R interval  
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10 200 differences greater than 50 ms (pNN50), and the difference of the quadratic mean of the  
11  
12 201 successive R-R normal intervals (RMSSD). Those variables are most commonly adopted in  
13  
14 202 scientific studies with physical exercise (Fortes et al., 2017; Penna et al., 2018). The SDNN  
15  
16 203 and RMSSD values were presented in milliseconds (ms).

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21 205 *Visual analogue scale (VAS)*. We assessed the participants' subjective ratings of  
22  
23 206 mental fatigue using the 100 mm VAS's as previously adopted (Franco-Alvarenga et al.,  
24  
25 207 2019). This scale has two extremities anchored from 0 (none at all) to 100 (maximal). No  
26  
27 208 other descriptor was presented in the VAS. The participants were required to answer by  
28  
29 209 making a horizontal mark on the 100 mm scale, "How mentally fatigued you feel now?" To  
30  
31 210 later quantify these values, we measured the millimeter distance from 0 to the mark made by  
32  
33 211 the participant. The evaluation was conducted individually (i.e., only swimmer and researcher  
34  
35 212 were in the room). The ICC was 0.94 (CI<sub>95%</sub> = 0.88 to 0.97) for VAS.

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37 213

38 214 *Stroop task*. We used a version of the Stroop task (Graf et al., 1995) to assess  
39  
40 215 inhibitory control and selective attention, both considered components of cognitive  
41  
42 216 functioning. Two assessments (pre and post-time exposure to smartphone or video) were  
43  
44 217 performed for each experimental condition. On this task, according to instructions given,  
45  
46 218 participants responded to color words either by giving the color of the ink in which a word  
47  
48 219 was printed or by reading the color name. Since the color of the words might be different  
49  
50 220 from what was typed (e.g. the word "blue" might show up in the "red" color, the word  
51  
52 221 "green" in "blue", and so on), this task required respondents to rapidly shift their mental set.  
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## MENTAL FATIGUE AND SWIMMING

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3 222 They were presented with a stimulus of 30 words with an interval of 200 ms between their  
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5 223 response and a new stimulus. The stimulus did not fade from the screen until a response was  
6  
7 224 given. Stimuli varied between congruent stimuli (those for which the word name and ink  
8  
9 225 color have the same meaning), incongruent (the word name and ink color have a different  
10  
11 226 meaning), and control (a colored rectangle with one of the colors of the test: red, green, blue,  
12  
13 227 and black). Respondents pressed computer keyboard keys to respond: D (red), F (green), J  
14  
15 228 (blue), and K (black). The stimulus disappeared when the answer was correct, and then a new  
16  
17 229 one was set. An X showed up on the screen in case of incorrect answers, and, then, a new  
18  
19 230 stimulus appeared. The accuracy of the correct answers and response time were collected at  
20  
21 231 the end of the test and the evaluator was blinded (i.e., the evaluator didn't know what the  
22  
23 232 participant's experimental condition was) for the assessments and had previous training for  
24  
25 233 the test. The tests were performed on a full-HD screen (1800 × 1260 pixels) laptop  
26  
27 234 (MacBook Pro, A1502 model, USA).

235

236 ***Statistical analysis***

237 The Shapiro-Wilk test evaluated data distribution. The Levene test verified  
238 homoscedasticity. Measures of central tendency (mean) and dispersion (standard deviation)  
239 described the research variables. Repeated-measures analysis of variance (ANOVA)  
240 compared the 50-m freestyle performance (baseline versus 50CON versus 50MF) between  
241 the experimental treatments. A factorial repeated-measure ANOVA with a mixed design 2x2  
242 (100-m freestyle) and 2x4 (200-m freestyle) analyzed the treatment (100-CON versus  
243 100MF; 200-CON, versus 200-MF) × lap interaction (every 50-m) for the pacing in 100 and  
244 200-m freestyle, respectively. A factorial repeated-measure ANOVA with a mixed design  
245 was used to analyze the treatment (50-CON versus 100-CON versus 200-CON versus 50-MF  
246 versus 100-MF versus 200-MF) × time interaction (pre-experiment versus post-experiment)

247 for HRV (SDNN, pNN50, and RMSSD) and CMJ. The same test was used to analyze the  
248 treatment (50-CON versus 100-CON versus 200-CON versus 50-MF versus 100-MF versus  
249 200-MF)  $\times$  time interaction (pre-smartphone or TV versus post-smartphone or TV) for the  
250 Stroop task (accuracy and response time) and VAS scale. A Bonferroni post-hoc test was  
251 used to identify possible statistical differences. In addition, the effect size (ES) at the pre-  
252 experiment versus post-experiment [eta squared ( $\eta^2$ )] revealed differences from a practical  
253 point of view. The following criteria were applied according to the Cohen (1992) guidelines  
254 for highly trained participants:  $\eta^2 < 0.2$  = trivial ES,  $0.2 \leq \eta^2 < 0.5$  = small ES,  $0.5 \leq \eta^2 < 0.8$   
255 = medium ES, and  $\eta^2 \geq 0.8$  = large ES. Data were processed in the Statistical Package for  
256 Social Sciences Version 21.0 (IBM Corp., Armonk, NY, USA) with a significance level of  
257 5%.”

## 259 Results

260 The descriptive data for variables of interest at baseline are shown in Table 1.

262 \*\*\*Table 1 insert here\*\*\*

### 264 *Mental Fatigue*

265 *Stroop task.* Regarding Stroop task accuracy, there was no significant main effect for  
266 condition ( $F_{(6, 19)} = 0.45$ ;  $p = 0.80$ ;  $\eta^2 = 0.02$ ; ES trivial) or time ( $F_{(2, 23)} = 1.02$ ;  $p = 0.32$ ;  $\eta^2 =$   
267 0.04), and, similarly, there was no significant interaction effect ( $F_{(8, 17)} = 0.31$ ;  $p = 0.90$ ;  $\eta^2 =$   
268 0.01; ES trivial).

269 Regarding Stroop task response time, there was a main effect for both condition ( $F_{(6,$   
270  $19)} = 6.03$ ;  $p = 0.01$ ;  $\eta^2 = 0.20$ ; ES small) and time ( $F_{(2, 23)} = 84.55$ ;  $p = 0.01$ ;  $\eta^2 = 0.78$ ; ES  
271 medium). There was also a significant condition  $\times$  time interaction ( $F_{(8, 17)} = 17.10$ ;  $p = 0.01$ ;

## MENTAL FATIGUE AND SWIMMING

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1  
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3 272  $\eta^2 = 0.42$ ; ES small). On separate tests for the races of varying distances, there were no  
4  
5 273 significant differences in response time for comparisons of 50CON to 100CON ( $p = 0.83$ )  
6  
7 274 and 200CON ( $p = 0.78$ ) or a comparison between 100CON and 200CON ( $p = 0.55$ ).  
8  
9  
10 275 However, collectively, the mental fatigue or smartphone app use conditions (50MF, 100MF,  
11  
12 276 and 200MF) demonstrated a significantly higher response time than the conditions with no  
13  
14 277 smartphone app use (50CON, 100CON, and 200CON;  $p = 0.01$ ). There were no significant  
15  
16 278 differences between 50MF, 100MF, and 200MF for Stroop response time ( $p = 0.50$ ).  
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20  
21 280 *VAS*. The results showed a significant condition effect ( $F_{(6, 19)} = 95.48$ ;  $p = 0.01$ ;  $\eta^2 =$   
22  
23 281  $0.80$ ; ES large) for the VAS subjective rating of mental fatigue. There was also a significant,  
24  
25 282 time effect for subjective rating of mental fatigue ( $F_{(2, 23)} = 985.97$ ;  $p = 0.01$ ;  $\eta^2 = 0.98$ ; ES  
26  
27 283 large) was found. Additionally, there was a significant condition x time interaction for  
28  
29 284 subjective rating of mental fatigue ( $F_{(8, 17)} = 129.80$ ;  $p = 0.01$ ;  $\eta^2 = 0.84$ ; ES large). There was  
30  
31 285 no significant difference in subjective ratings of mental fatigue between 50CON and  
32  
33 286 100CON ( $p = 0.36$ ), between 50CON and 200CON ( $p = 0.62$ ), or between 100CON and  
34  
35 287 200CON ( $p = 0.93$ ). However, the mental fatigue or smartphone app use conditions (50MF,  
36  
37 288 100MF, and 200MF) demonstrated a significantly higher subjective rating of mental fatigue  
38  
39 289 relative to the no smartphone app use control conditions (50CON, 100CON, and 200CON;  $p$   
40  
41 290  $= 0.01$ ). There were no significant differences between 50MF, 100MF, and 200MF for  
42  
43 291 subjective rating of mental fatigue ( $p = 0.72$ ).  
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51 293 ***50, 100, and 200-m freestyle performance***

52  
53 294 *50-m freestyle performance*. There was no significant difference between 50CON and  
54  
55 295 50MF for 50-m freestyle performance (Figure 2A;  $F_{(2, 23)} = 0.63$ ;  $p = 0.81$ ;  $\eta^2 = 0.02$ ; ES  
56  
57 296 trivial).  
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## MENTAL FATIGUE AND SWIMMING

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3 2974  
5 298 *100-m freestyle performance.* There was a significant main effect for both condition6  
7  
8 299 468 ( $F_{(2, 23)} = 66.63; p = 0.01; \eta^2 = 0.73$ ; ES medium) and time ( $F_{(2, 23)} = 6694.17; p = 0.01;$ 9  
10  
11 300  $\eta^2 = 1.00$ ; ES large), and there was also a significant condition x time interaction (Figure 2B;12  
13 301  $F_{(4, 21)} = 8.95; p = 0.01; \eta^2 = 0.27$ ; ES small) for 100-m freestyle performance. While there14  
15 302 was no significant performance difference in the first 50 meters of the 100-m freestyle16  
17 303 between 100MF and 100CON conditions (see Figure 3), participants in the 100MF condition18  
19 304 demonstrated a significantly lower performance in the second 50 meters relative to those in20  
21 305 conditions in the first 50 meters (Figure 3) ( $p = 0.91$ ), the third 50 meters ( $p = 0.07$ ), or the22  
23 306 100CON condition (Figure 3;  $p = 0.02$ ). Overall, participants in the 100MF condition24  
25 307 performed more slowly than those in the 100CON condition ( $p = .01$ ).26  
27 30828  
29 309 *200-m freestyle performance.* There was a significant main effect for both condition30  
31 310 ( $F_{(2, 23)} = 71.40; p = 0.01; \eta^2 = 0.77$ ; ES medium) and time ( $F_{(2, 23)} = 6855.07; p = 0.001; \eta^2 =$ 32  
33 311 1.14; ES large), and there was also a significant condition x time interaction (Figure 2C;  $F_{(4,$ 34  
35 312  $_{21)} = 11.72; p = 0.01; \eta^2 = 0.42$ ; ES small) for 200-m freestyle performance. There was no36  
37 313 significant difference between performances of participants in 200MF and 200CON38  
39 314 conditions in the first 50 meters (Figure 3) ( $p = 0.91$ ), the third 50 meters ( $p = 0.07$ ), or the40  
41 315 fourth 50 meters ( $p = 0.06$ ). However, participants in the 200MF condition demonstrated a42  
43 316 significantly lower performance in the second 50-meters than those the 200CON condition44  
45 317 (Figure 3;  $p = 0.01$ ). There was a significant overall difference between 200MF and 200CON46  
47 318 486 conditions for the 200-m freestyle performance ( $p = 0.01$ ).48  
49 31950  
51 320 **\*\*\*Figures 2 & 3 insert here\*\*\***52  
53 321

322 \*\*\*Figure 3 insert here\*\*\*

323

324 **CMJ**

325 Regarding CMJ, there was a significant main effect for both condition ( $F_{(6, 19)} =$   
326  $48.91; p = 0.01; \eta^2 = 0.67; ES = \text{medium}$ ) and time ( $F_{(2, 23)} = 50.71; p = 0.01; \eta^2 = 0.68; ES =$   
327  $\text{medium}$ ), and there was also a significant condition x time interaction ( $F_{(8, 17)} = 55.76; p =$   
328  $0.01; \eta^2 = 0.70; ES \text{ medium}$ ). On separate tests for the races of varying distances, there were  
329 significant differences in CMJ for comparisons of 200 (200MF and 200CON) to 100 (100MF  
330 and 100CON) and 50-meters (50MF and 50CON) ( $p = 0.01$ ). There were a significant  
331 differences in CMJ for comparisons of 100 (100MF and 100CON) to 50-meters (50MF and  
332 50CON) ( $p = 0.01$ ). All experimental conditions showed decreased CMJ performance in  
333 post-experiment ( $p = 0.01$ ).

334

335 **HRV indicators**

336 There was a significant main condition effect for R-R interval ( $F_{(6, 19)} = 62.48; p =$   
337  $0.01; \eta^2 = 0.72; ES \text{ medium}$ ), SDNN ( $F_{(6, 19)} = 193.44; p = 0.01; \eta^2 = 0.89; ES \text{ large}$ ),  
338 RMSSD ( $F_{(6, 19)} = 230.80; p = 0.01; \eta^2 = 0.90; ES \text{ large}$ ), and pNN50 ( $F_{(6, 19)} = 161.93; p =$   
339  $0.01; \eta^2 = 0.87; ES \text{ large}$ ). There was also a main time effect for R-R interval ( $F_{(6, 19)} =$   
340  $206.27; p = 0.01; \eta^2 = 0.89; ES = \text{large}$ ), SDNN ( $F_{(6, 19)} = 286.80; p = 0.01; \eta^2 = 0.92; ES$   
341  $\text{large}$ ), RMSSD ( $F_{(6, 19)} = 438.32; p = 0.01; \eta^2 = 0.94; ES \text{ large}$ ), and pNN50 ( $F_{(6, 19)} = 253.83;$   
342  $p = 0.01; \eta^2 = 0.92; ES \text{ large}$ ). There was a significant condition x time interaction for R-R  
343 interval ( $F_{(6, 19)} = 48.74; p = 0.01; \eta^2 = 0.67; ES \text{ medium}$ ), SDNN ( $F_{(6, 19)} = 241.48; p = 0.01;$   
344  $\eta^2 = 0.91; ES \text{ large}$ ), RMSSD ( $F_{(6, 19)} = 238.81; p = 0.01; \eta^2 = 0.90; ES \text{ large}$ ), and pNN50  
345 ( $F_{(6, 19)} = 199.40; p = 0.01; \eta^2 = 0.89; ES \text{ large}$ ). For all experimental conditions, we observed

## MENTAL FATIGUE AND SWIMMING

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3 346 decreased values for the R-R interval, SDNN, RMSSD and pNN50 from initial to post-  
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5 347 experiment (30-minutes) ( $p = 0.01$ ). There were significant differences in R-R interval,  
6  
7 348 SDNN, RMSSD, and pNN50 for comparisons of 200 (200MF and 200CON) to 100 (100MF  
8  
9 349 and 100CON) and 50-meters (50MF and 50CON) ( $p = 0.01$ ). There were also significant  
10  
11 350 differences in R-R interval, SDNN, RMSSD, and pNN50 for comparisons of 100 (100MF  
12  
13 351 and 100CON) to 50-meters (50MF and 50CON) ( $p = 0.01$ ).  
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**Discussion**

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21 354 The results of this study showed that social media apps on smartphones for prolonged  
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23 355 periods (i.e., 30-minutes) caused mental fatigue (i.e., impaired Stroop task response time and  
24  
25 356 increased VAS), while 30-minutes watching videos about Olympic Games on an 84-inch  
26  
27 357 screen caused no changes in mental fatigue indicators (i.e., Stroop task response time and  
28  
29 358 VAS). The main findings showed that mental fatigue impaired performance in 100 and 200-  
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31 359 m freestyle without changing the pacing. No impairments for the 50-m freestyle performance  
32  
33 360 in international-level swimmers occurred. So, the hypotheses of the present study were  
34  
35 361 partially supported by the results.  
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40 362 The present investigation indicated that the use of smartphone social media apps  
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42 363 (WhatsApp, Instagram, and Facebook) for 30-min attenuates response time in the Stroop task  
43  
44 364 and increases the subjective rating of mental fatigue, supporting other findings (Fortes et al.,  
45  
46 365 2019). The main mechanisms that might explain the mental fatigue are an increase of theta  
47  
48 366 wave in the prefrontal cortex (Franco-Alvarenga et al., 2019), an increase of adenosine  
49  
50 367 concentration in the anterior cingulate cortex (Martin et al., 2018), inhibition of dopamine  
51  
52 368 neurotransmission receptor in the brain (Smith et al., 2018), reduction of brain glycoses  
53  
54 369 (Martin et al., 2018), and attenuation of brain oxygenation (Russel, Jenkins, Smith, Halson, &  
55  
56 370 Kelly, 2019b). Also, scientific evidence shows that the mental fatigue might reduce sports  
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## MENTAL FATIGUE AND SWIMMING

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3 371 performance (Fortes et al., 2019; Coutinho et al., 2018; Moreira et al., 2018), including in  
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5 372 swimming (Penna et al., 2018).

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8 373 For the 50-m freestyle performance, our results revealed no difference between  
9  
10 374 50CON and 50MF conditions. Kalva-Filho et al. (2015) found that adenosine triphosphate,  
11  
12 375 muscular glycogen storage, reaction time on the starting block, and muscular strength  
13  
14 376 capacity are determinants for the 50-m freestyle performance. Considering that 50-m  
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16 377 freestyle total time in the physical effort is inferior to 30-s in high-level swimmers  
17  
18 378 (McGibson et al., 2018), the task is considered of high intensity and short duration. Some  
19  
20 379 studies also showed no effect of mental fatigue on physical performance in high intensity and  
21  
22 380 short duration (Pageux, Marcora, & Leppers, 2013; Smith, Marcora, & Coutts, 2015).  
23  
24 381 Coutinho et al. (2018), when analyzed soccer players, showed that the acceleration in small-  
25  
26 382 sided games was similar between mental fatigue and control conditions. In the present study,  
27  
28 383 the results for CMJ showed no differences in post-experiment between mental fatigue and  
29  
30 384 control conditions, supporting the scientific literature. It seems that mental fatigue does not  
31  
32 385 affect physical performance in high intensity and short time.

33  
34 386 For the 100-m and 200-m freestyle performances, we found an impaired performance  
35  
36 387 following smartphone social media app use (100MF and 200MF) compared to control  
37  
38 388 conditions (100CON and 200CON). The percentage differences between experimental  
39  
40 389 conditions (MF vs. CON) was approximately 2.0%. In professional athletes, this small  
41  
42 390 percentage represents the difference between the winner and fourth place. For example, in the  
43  
44 391 2019 World Championship, the time difference between the winner (Dressel) and fourth  
45  
46 392 place (Chiereghini) in the 100-m freestyle race was 0.92 s, 1.95% difference (FINA, 2019).

47  
48 393 A systematic review with metanalysis showed that mental fatigue impairs physical  
49  
50 394 performance on high-intensity tasks with durations greater than one-minute (McMorris et al.,  
51  
52 395 2018). The psychobiological theory (Marcora et al., 2009) explains the impaired performance  
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## MENTAL FATIGUE AND SWIMMING

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3 396 in 100 and 200-m freestyle. In a mentally fatigued athlete, the increased perception of effort  
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5 397 and lack of energy might impair physical tasks of moderate and long duration, that is, the  
6  
7 398 athlete will reduce speed and intensity to regulate the higher rate of perceived exertion  
8  
9 399 (Franco-Alvarenga et al., 2019; Marcora et al., 2009).

10  
11  
12 400 Regarding the participants' pacing (i.e., variant performances in each 50-m segment of  
13  
14 401 the races), performance was similar between participants in mental fatigue conditions  
15  
16 402 (100MF and 200MF) and control conditions (100CON and 200CON). In the 100MF  
17  
18 403 condition, athletes performed the first 50-m adopting the same effort as in the 100CON.  
19  
20 404 However, in the second 50-m, performance was impaired in the mentally fatigued group  
21  
22 405 relative to the control group. For the 200-m, the mentally fatigued participants showed  
23  
24 406 relative difficulty only for the second 50-m. The pacing adopted by athletes in both races  
25  
26 407 (100 and 200-m freestyle) was a positive shape (McGibson et al., 2018). Franco-Alvarenga et  
27  
28 408 al. (2019) revealed reduced performance in the 20-km time trial with trained cyclists in a  
29  
30 409 mental fatigue state, although the authors identified no difference for pacing ("J" shaped).  
31  
32 410 Despite differences in the participants between the present study (using international-level  
33  
34 411 swimming athletes) and other scientific investigations (using athletes of different sports), our  
35  
36 412 results for 100 and 200-m freestyle performances support past scientific literature for pacing.

37  
38 413 Concerning HRV indicators (R-R interval, SDNN, RMSSD, and pNN50), we found  
39  
40 414 that, after the race, the HRV indicators were reduced, regardless of the mental fatigue  
41  
42 415 manipulation. There was no effect of mental fatigue on HRV (Fortes et al., 2019; Penna et al.,  
43  
44 416 2018). It seems that the brain areas activated by mental fatigue are different from those  
45  
46 417 activated by the autonomic nervous system. For mental fatigue, the intensity and amplitude of  
47  
48 418 theta wave in the anterior cingulate cortex and prefrontal cortex increase significantly  
49  
50 419 (Franco-Alvarenga et al., 2019; Martin et al., 2018). On the other hand, for HRV, the  
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52 420 intensity and amplitude of beta waves in the left insular cortex increase considerably (Okano  
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3 421 et al., 2015). Other studies showed that the magnitude of HRV reduction after physical effort  
4  
5 422 relates to the duration or task volume (Nakamura et al., 2015; Vilamitjana et al. 2014),  
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7  
8 423 explaining the findings in the present study.  
9

10 424 Although the present study presented novel and important findings, some limitations  
11  
12 425 must be mentioned. The ‘mental load’ during smartphone use was not standardized. Theta  
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14 426 wave in the electroencephalogram (EEG), a mental fatigue indicator, was not measured, as  
15  
16 427 well as internal training load (PSE-session method). Also, styles such as 400-m freestyle,  
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18 428 400-m medley, and 200-m butterfly were not measured. In this sense, we recommend that  
19  
20 429 future investigations include EEG to demonstrate mental fatigue via theta band, measures of  
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22 430 the internal training load, and other swimming styles in the experiment. Meanwhile, current  
23  
24 431 findings should be considered with caution.  
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28 432 From a practical standpoint, our study demonstrated that prolonged use (more than 30-  
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30 433 min) of smartphone social media apps (WhatsApp, Instagram, and Facebook) have a  
31  
32 434 detrimental performance effect and should be forbidden before races for international-level  
33  
34 435 swimming athletes. Also, it is important to determine whether an athlete is mentally fatigued  
35  
36 436 before races (a Stroop task might be performed before races). If so, coaches should define  
37  
38 437 strategies to reduce mental fatigue impairments. The mental fatigue might define a  
39  
40 438 championship winner, mainly in high-performance athletes. Thus, it must be considered an  
41  
42 439 important feature in competitions.  
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## 48 49 441 **Conclusion**

50  
51 442 Our results showed that mental fatigue reduced the performance in 100 and 200-m  
52  
53 443 freestyle in international-level swimmers, but the 50-m freestyle performance was not  
54  
55 444 impaired. It seems that the mental fatigue caused by social media apps impairs 100 and 200-  
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445 m freestyle performance, but not in physical efforts smaller than 30-s duration as in 50-m  
446 freestyle.

447

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## MENTAL FATIGUE AND SWIMMING

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## MENTAL FATIGUE AND SWIMMING

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3 554 Table 14 555 *Descriptive data of variables in baseline*

<b>Variable</b>	<b>Mean</b>	<b>Standard deviation</b>
Age (years)	20.44	2.06
Body mass (kg)	72.00	9.00
Stature (m)	1.81	0.07
50-m freestyle (s)	24.96	1.87
100-m freestyle (s)	55.26	3.20
200-m freestyle (s)	121.39	6.75
CMJ (cm)	42.55	3.52
SDNN (ms)	78.24	15.46
pNN50 (%)	48.24	16.77
RMSSD (ms)	50.90	10.05

556 *Note.* CMJ = countermovement jump; SDNN = the standard deviation of all NN intervals; pNN50 = the successive percentage  
 557 of R-R interval differences greater than 50 ms.

MENTAL FATIGUE AND SWIMMING

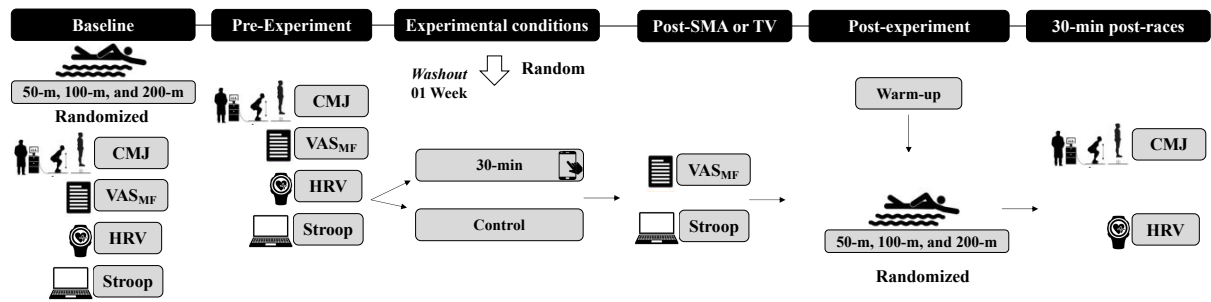


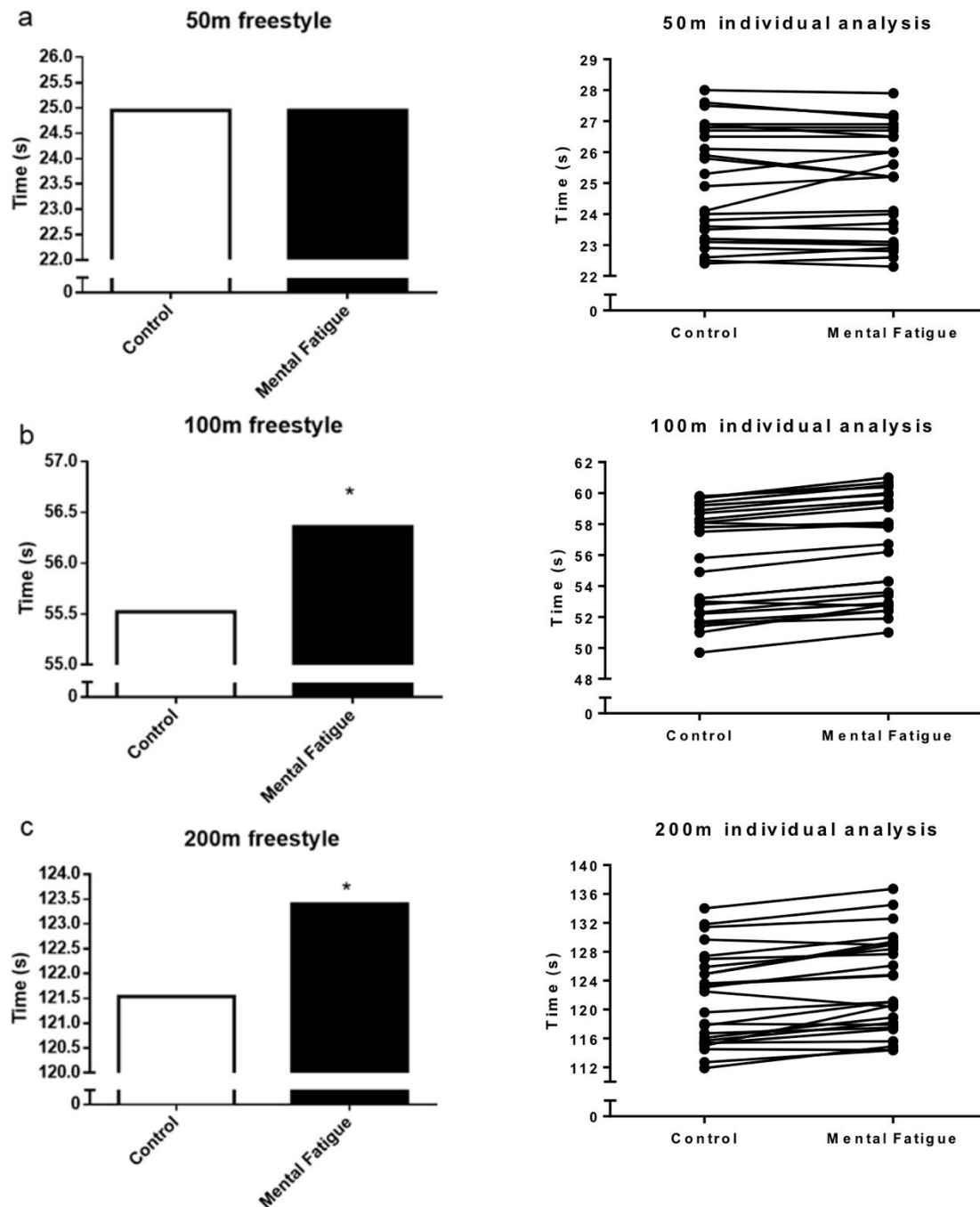
Figure 1

*Experimental design of study*

Note. SMA = smartphone; CMJ = countermovement jump; VAS<sub>MF</sub> = Mental Fatigue Visual Analogue Scale; HRV = heart rate variability.

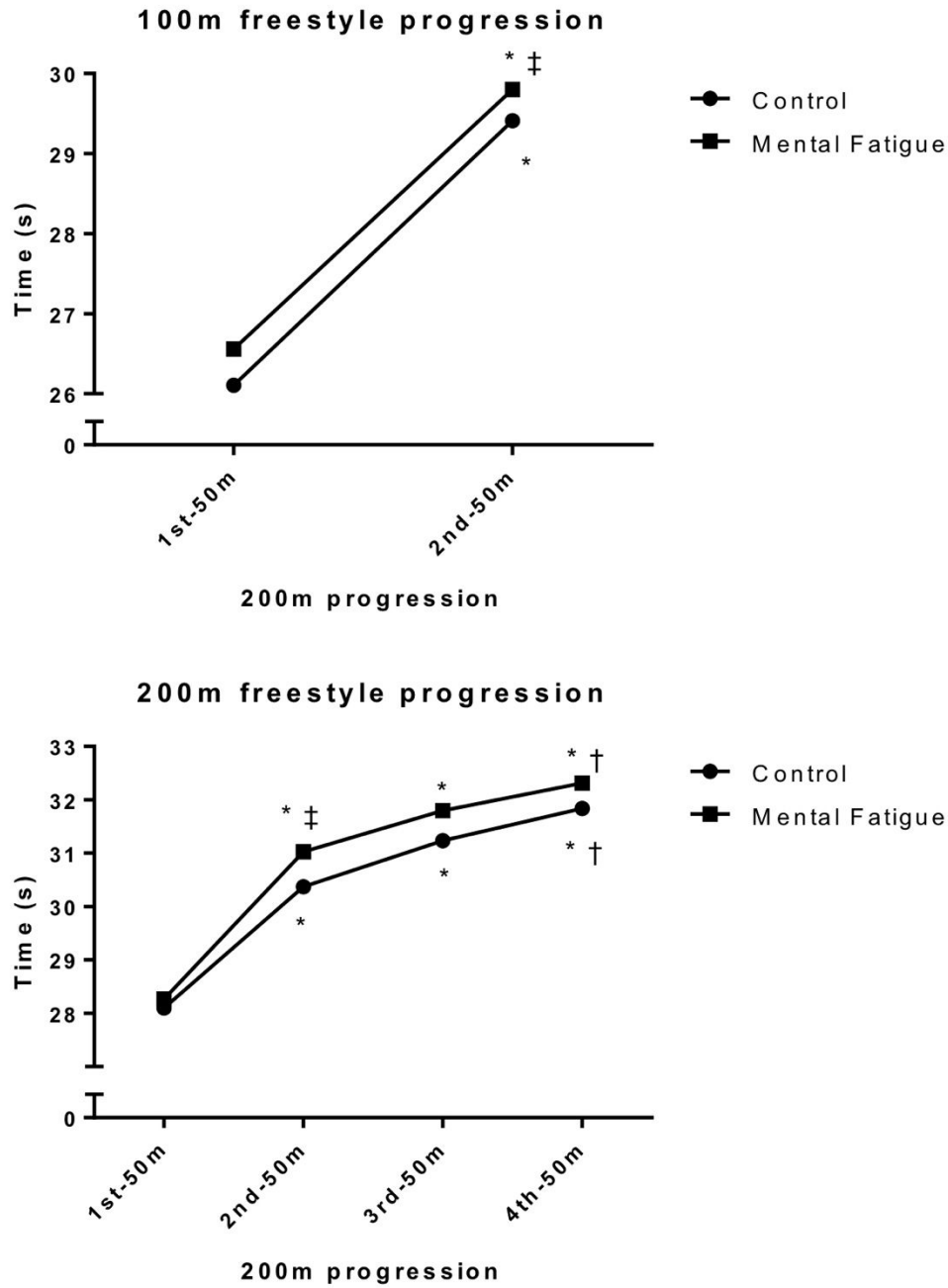
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MENTAL FATIGUE AND SWIMMING



563 Figure 2  
 564 50 (A), 100 (B) and 200-m (C) freestyle performance according to experimental condition (control vs. mental  
 565 fatigue) in professional swimmers.  
 566 Note. \* $p < 0.05$  to control condition.  
 567

MENTAL FATIGUE AND SWIMMING



568  
 569 Figure 3  
 570 Pacing strategy (every 50-m) for 100 and 200-m freestyle performance in professional swimmers  
 571 Note. \* = different from 1st-50m; † = different from 2nd-50m; ‡ = different from control.

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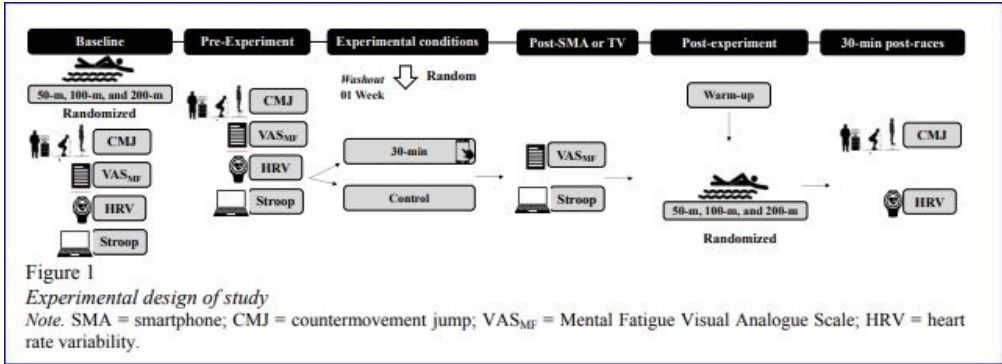


Figure 1

169x61mm (96 x 96 DPI)

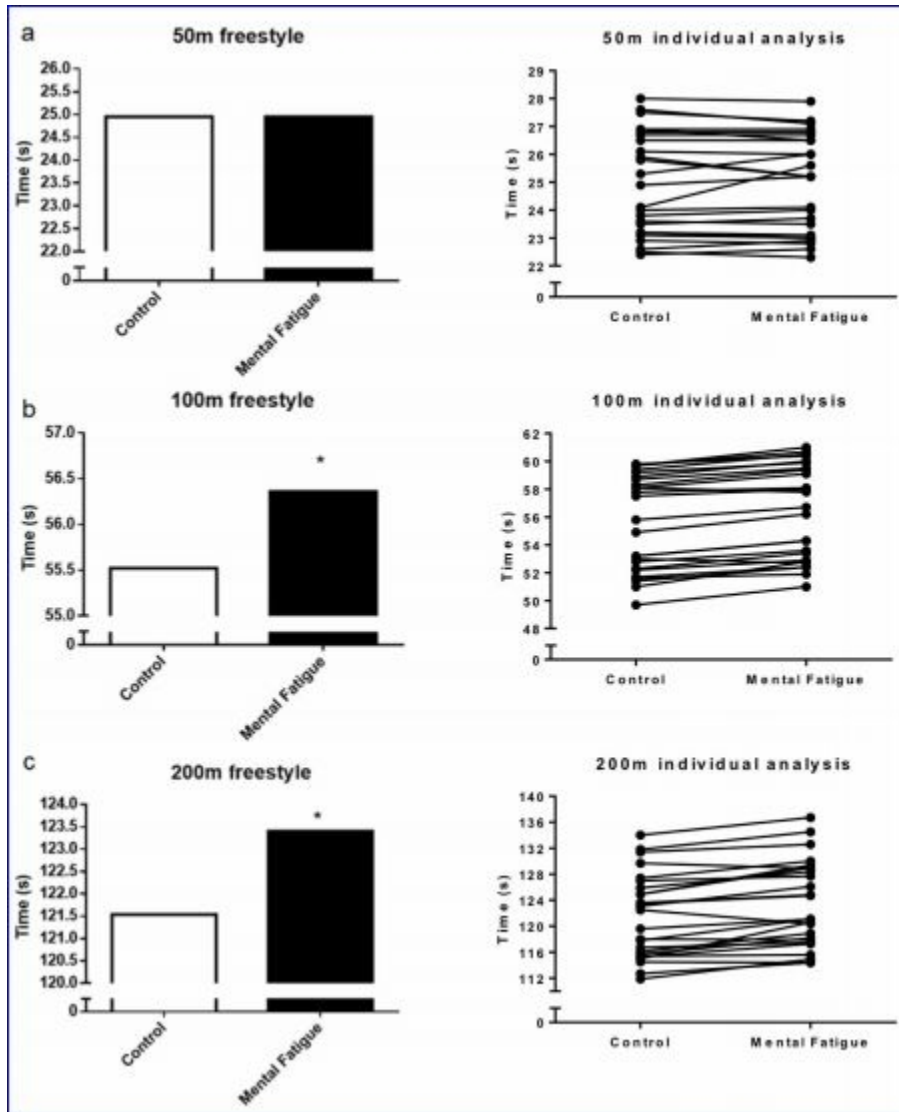


Figure 2

119x146mm (96 x 96 DPI)

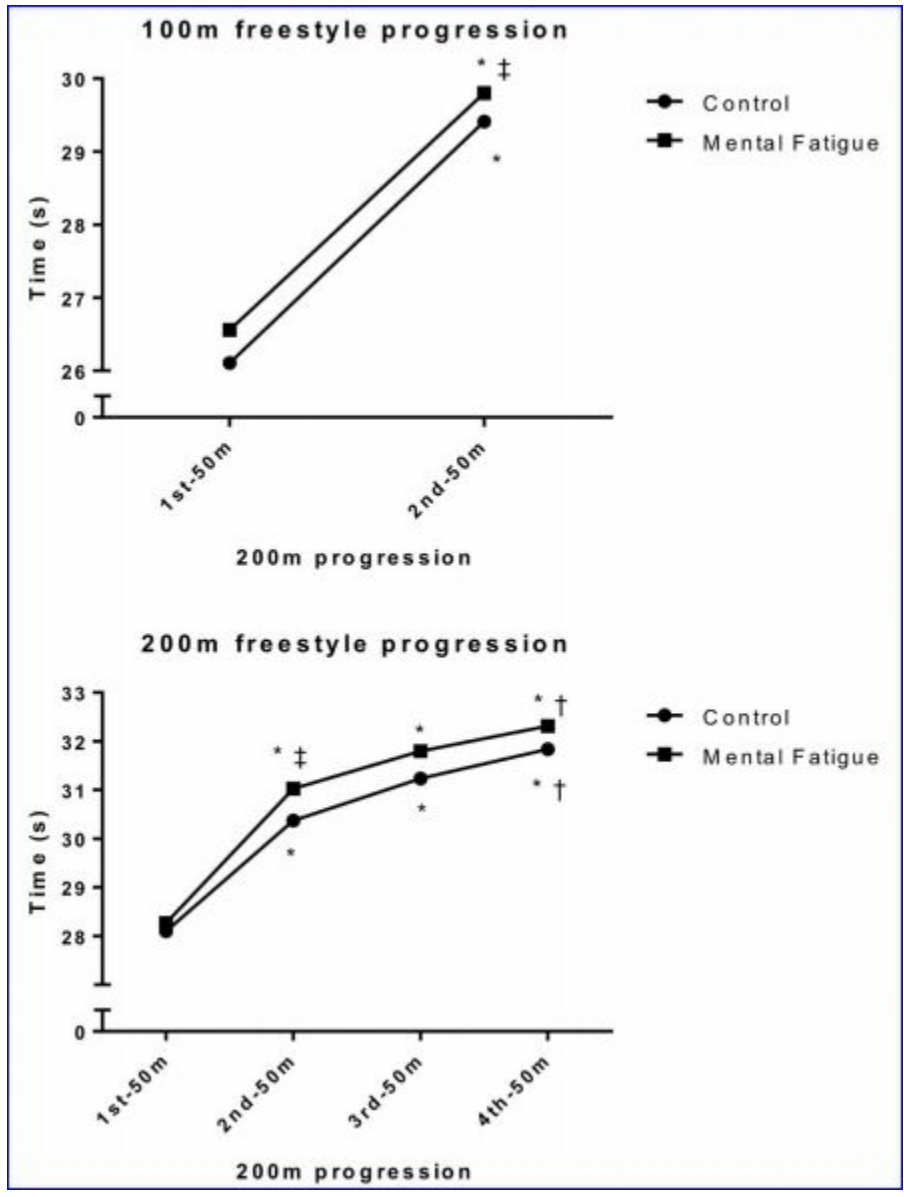


Figure 3

118x156mm (96 x 96 DPI)