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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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.

1 **Smartphone Use Among High Level Swimmers Is Associated with Mental**

2 **Fatigue and Slower 100- and 200- but not 50-meter Freestyle Racing**

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.

Introduction

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

According to Bangsbo (2015), success in this sport depends on a well-developed set of physical (e.g., anaerobic capacity, anaerobic, and aerobic power), cognitive (e.g., attention, inhibitory control, cognitive flexibility, coping, and emotional control), technical (e.g., underwater ripple and turn), and tactical (e.g., pace strategy) abilities. In sports like cycling and swimming, executive functions (e.g., attention and inhibitory control) also play an important role in performance. Block reaction time requires well-trained attention, and pace strategy requires well developed inhibitory control (Franco-Alvarenga et al., 2019). Inhibitory control is a core executive function related for successful task performance (Diamond, 2015). A reduction in attention and inhibitory control would be expected to impair performance, especially in races that require sustained effort (e.g., 100 and 200-m freestyle). A mentally fatigued athlete might experience reduced attention and inhibition control (Fortes et al., 2019; Franco-Alvarenga et al., 2019).

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

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

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

65 Mental fatigue may impair physical performance on tasks with a duration greater than
66 30-seconds, as an integrative literature review has found (Martin et al., 2018). Another
67 systematic literature review reported a detrimental effect of mental fatigue on athletes'
68 physical performance (Cutsem et al., 2017). However, to the best of our knowledge, only one
69 study has analyzed the effects of mental fatigue on swimming performance (Penna et al.,
70 2018). The protocol for inducing mental fatigue in this past study was a Stroop task (Graf,
71 Uttl, & Tuokko, 1995), which lacked ecological validity in that athletes in a real world
72 competition do not engage in this task. A better research design might use an ecologically

valid task to analyze the effects of smartphone social media app use on sports performance (i.e., swimming). From a practical standpoint, discovering the effects of social media exposure through smartphones on athletes' subsequent performance on the 50-, 100-, and 200-m freestyle race might suggest new pre-competition protocols, perhaps including avoidance of smartphone use before races. We analyzed the effect of international-level swimmers' use of social media smartphone apps on their 50-, 100-, and 200-m freestyle performances. We hypothesized that 30-minutes of exposure time to smartphone applications both sexes of these swimmers would be associated with slower swim times on 50, 100, and 200-m freestyle races among

Method

Participants

We conducted an a priori calculation to estimate our required sample size, using the equation n = 8e2/d2 where n, e, and d denote the required sample size, coefficient of variation, and magnitude of the treatment, respectively. We assumed a coefficient of variation of 1.1 % for the 100-m freestyle performed by international swimmers (McGibson et al., 2018) and a conservative d of 1.0 %, and this calculation resulted in an estimated requirement for ~ 15 participants.

Considering possible participant attrition, we recruited 25 international-level swimmers (M age = 20.4 years, SD = 2.06; M height = 1.81 meters, SD = 0.07; M weight = 72.00 kg, SD = 9) from two swim clubs in Brazil. There were 14 men (according to International Points Score of Fédération Internationale de Natation - FINA: M = 851.59, SD = 19.14 points for the 50-m freestyle; M = 856.68, SD = 21.90 points for the 100-m freestyle; and M = 847.46, SD = 24.31 points for the 200-m freestyle) and 11 women (FINA Points Score: M = 893.25, SD = 20.90 points for the 50-m freestyle; M = 885.42, SD = 17.63 points for the 100-m freestyle; and *M* = 866.04, *SD* =23.87 points for the 200-m freestyle. Participants had trained an average of 5.8 (*SD* = 0.5) sessions/week for an average of 42.5 km (*SD* = 6.2) swum per week, and they had ~ 8.4 years experience swimming in international women present different responses to stress and to muscle fatigue, Lopes et al. (2020) showed no sex differences in the magnitude of decrements in aerobic performance among (e.g., energy drink) or alcoholic beverages and to avoid intense exercise for 48 hours preceding their swimming sessions. They were also instructed to avoid consumption of coffee and national tournaments. Although Pageaux and Lepers (2018) indicated that men and mentally fatigued professional runners.

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

Experimental design and procedure

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

Baseline visits

During the three baseline visits, we collected data for heart rate variability (HRV) reproducibility, the countermovement jump (CMJ) task, a Stroop task, and a participant selfreport on the Mental Fatigue Visual Analogue Scale (VAS) following 50, 100, and 200-m freestyle swims. Next, we randomized the order of the six experimental conditions or each participant using a random number table generator (www.randomizer.org). The six conditions were to swim each of the three swim distances with a prior mental fatigue inducement (i.e., 50-MF, 100-MF, and 200-MF) and without a prior mental fatigue inducement (i.e., 50-CON, 100-CON, and 200-CON). A one-week washout period separated each of these swims (see Figure 1). As noted above, the participants maintained their training routines during the washout period. The participants abstained from any physical exercise, alcohol ingestion 48-h before all experimental sessions, and they abstained from caffeine for at least three hours before all experimental sessions.

Experimental sessions

At each experimental session, we used the Stroop task to assess, rather than induce mental fatigue. Assessments ocurred both before and after either smartphone use (the mental fatigue inducement) or watching a documentary TV show about the Olympic Games (a control or non-mental fatigue experience). We recommended that the athletes ingest fluid ad libidum up to two hours before each experimental session. Smartphone use two hours before each experimental session was forbidden. The participants warmed-up for five minutes in a swimming pool. Next, in consideration of the post-activation potential phenomenon identified by Wilson et al. (2013), we gave participants another five minute warm-up interval before beginning the simulated race (50, 100, or 200-m freestyle). Finally, the athletes swam the simulated race (i.e, the 50, 100 or 200-m freestyle), adopting the official rules of the sport. During the simulated swimming race (50, 100 or 200-m freestyle), a researcher who was blind to the participant's experimental treatment condition, provided participants continuous verbal encouragement. We measured CMJ and HRV before and ~30 minutes after each experimental session.

*****Figure 1 insert here*****

Control and mental fatigue protocols

In the non-mental fatigue or control conditions (i.e., the 50-CON, 100-CON, and 200-CON conditions), participants watched 30 minutes of coaching videos about Olympic Games on an 84-inch screen (smartphone free room). Studies related to mental fatigue and human performance have long used these emotionally neutral 30-minute documentaries in control conditions (Marcora et al., 2009; Moreira et al., 2018) because neither cognitive performance (Fortes et al., 2019; Lopes et al., 2020) nor underlying brain mechanisms of mental fatigue are altered (Franco-Alvarenga et al., 2019).

We used social media app use on smartphones to induce mental fatigue in the experimental conditions (i.e., the 50-MF, 100-MF, and 200-MF conditions), Participants used social media apps (e.g., WhatsApp, Facebook, and Instagram) on smartphones for 30 minutes prior to these races. We supervised the smartphone use to ensure the athletes only used social media apps.

All participants (i.e., participants from both the experimental and control groups) remained in the same room together while either using their smartphone or watching the video. The participants were prohibited from speaking amongst themselves.

Measures

*50, 100, and 200-m freestyle swims*During the participants' simulated swimming competitions, we measured their performance using Electronic boards (Daktronics®, Brazil).

We divided participants into sets of four, according to their prior performance and sex (male or female). Participants remained in these same sets of four through all experimental conditions. During their five-minute warm-ups, participants performed swimming sprints of 10 meters each minute. Next, they engaged in five-minute rest intervals before the simulated race. We established this rest interval because of the potential post-activation phenomenon (Wilson et al., 2013). All athletes were familiar with and needed no instructions for the 50, 100, and 200-m freestyle simulated races. We measured their race time in seconds, and we gathered times for the completion of each 50-m segment of the longer (100 and 200-m) races in order to determine any differences in their pacing through the races.

Countermovement jump (CMJ). We used an electronic contact jump mat (Hidrofit®, Jump System, Belo Horizonte, Brazil) to analyze the CMJ height for each participant. Each participant performed three attempts with 30 second intervals between trials. We analyzed and the best attempt over these three trials. Participants performed the CMJ with their hands on their waists and no restrictions on the knee angle during the eccentric phase of the jump. Also, the participants were instructed to maintain their legs in a straight position during the flight phase and land at the take-off point. All participants were familiar with the test before the beginning of the investigation. In the present study, the participants' intraclass correlation coefficient was 0.99 ($CI_{95\%}$ = 0.98 to 0.99) for the CMJ, indicating good test reliability.

Heart rate variability (HRV). All evaluations were performed under the same conditions. Participants remained in the sitting position for 10 minutes before starting the resting HRV (Task Force, 1996). The R-R intervals (i.e., the distance between each heartbeat) were obtained using a portable heart rate telemetry tape with Bluetooth (Polar® H10, Kempele, Finland) in a sampling of 1,000 Hz and using a smartphone app (Elite HRV, Perrota, Jeklin, Hives, Meanwell, & Warburton, 2017) uninterruptedly for five minutes (Task Force, 1996) in a room with a temperature of 24^{o}C. We analyzed the following variables: the standard deviation of all NN intervals (SDNN), the consecutive percentage of R-R interval differences greater than 50 ms (pNN50), and the difference of the quadratic mean of the successive R-R normal intervals (RMSSD). Those variables are most commonly adopted in scientific studies with physical exercise (Fortes et al., 2017; Penna et al., 2018). The SDNN and RMSSD values were presented in milliseconds (ms).

Visual analogue scale (VAS). We assessed the participants' subjective ratings of mental fatigue using the 100 mm VAS's as previously adopted (Franco-Alvarenga et al., 2019). This scale has two extremities anchored from 0 (none at all) to 100 (maximal). No other descriptor was presented in the VAS. The participants were required to answer by making a horizontal mark on the 100 mm scale, "How mentally fatigued you feel now?" To later quantify these values, we measured the millimeter distance from 0 to the mark made by the participant. The evaluation was conducted individually (i.e., only swimmer and researcher were in the room). The ICC was 0.94 ($CI_{95\%}$ = 0.88 to 0.97) for VAS.

Stroop task. We used a version of the Stroop task (Graf et al., 1995) to assess inhibitory control and selective attention, both considered components of cognitive functioning. Two assessments (pre and post-time exposure to smartphone or video) were performed for each experimental condition. On this task, according to instructions given, participants responded to color words either by giving the color of the ink in which a word was printed or by reading the color name. Since the color of the words might be different from what was typed (e.g. the word "blue" might show up in the "red" color, the word "green" in "blue", and so on), this task required respondents to rapidly shift their mental set.

They were presented with a stimulus of 30 words with an interval of 200 ms between their response and a new stimulus. The stimulus did not fade from the screen until a response was given. Stimuli varied between congruent stimuli (those for which the word name and ink color have the same meaning), incongruent (the word name and ink color have a different meaning), and control (a colored rectangle with one of the colors of the test: red, green, blue, and black). Respondents pressed computer keyboard keys to respond: D (red), F (green), J (blue), and K (black). The stimulus disappeared when the answer was correct, and then a new one was set. An X showed up on the screen in case of incorrect answers, and, then, a new stimulus appeared. The accuracy of the correct answers and response time were collected at the end of the test and the evaluator was blinded (i.e., the evaluator didn't know what the participant's experimental condition was) for the assessments and had previous training for the test. The tests were performed on a full-HD screen (1800 × 1260 pixels) laptop (MacBook Pro, A1502 model, USA).

Statistical analysis

The Shapiro-Wilk test evaluated data distribution. The Levene test verified homoscedasticity. Measures of central tendency (mean) and dispersion (standard deviation) described the research variables. Repeated-measures analysis of variance (ANOVA) compared the 50-m freestyle performance (baseline versus 50CON versus 50MF) between the experimental treatments. A factorial repeated-measure ANOVA with a mixed design 2x2 (100-m freestyle) and 2x4 (200-m freestyle) analyzed the treatment (100-CON versus 100MF; 200-CON, versus 200-MF) × lap interaction (every 50-m) for the pacing in 100 and 200-m freestyle, respectively. A factorial repeated-measure ANOVA with a mixed design was used to analyze the treatment (50-CON versus 100-CON versus 200-CON versus 50-MF versus 100-MF versus 200-MF) × time interaction (pre-experiment versus post-experiment) for HRV (SDNN, pNN50, and RMSSD) and CMJ. The same test was used to analyze the treatment (50-CON versus 100-CON versus 200-CON versus 50-MF versus 100-MF versus 200-MF) × time interaction (pre-smartphone or TV versus post-smartphone or TV) for the Stroop task (accuracy and response time) and VAS scale. A Bonferroni post-hoc test was used to identify possible statistical differences. In addition, the effect size (ES) at the pre-experiment versus post-experiment [eta squared (η^2)] revealed differences from a practical point of view. The following criteria were applied according to the Cohen (1992) guidelines for highly trained participants: $\eta^2 < 0.2$ = trivial ES, $0.2 \leq \eta^2 < 0.5$ = small ES, $0.5 \leq \eta^2 < 0.8$ = medium ES, and $\eta^2 \geq 0.8$ = large ES. Data were processed in the Statistical Package for Social Sciences Version 21.0 (IBM Corp., Armonk, NY, USA) with a significance level of 5%."

Results

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

*****Table 1 insert here*****

Mental Fatigue

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

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

$\eta^2 = 0.42$; ES small). On separate tests for the races of varying distances, there were no significant differences in response time for comparisons of 50CON to 100CON ($p = 0.83$) and 200CON ($p = 0.78$) or a comparison between 100CON and 200CON ($p = 0.55$). However, collectively, the mental fatigue or smartphone app use conditions (50MF, 100MF, and 200MF) demonstrated a significantly higher response time than the conditions with no smartphone app use (50CON, 100CON, and 200CON; $p = 0.01$). There were no significant differences between 50MF, 100MF, and 200MF for Stroop response time ($p = 0.50$).

VAS. The results showed a significant condition effect ($F_{(6, 19)} = 95.48$; $p = 0.01$; $\eta^2 = 0.80$; ES large) for the VAS subjective rating of mental fatigue. There was also a significant, time effect for subjective rating of mental fatigue ($F_{(2, 23)} = 985.97$; $p = 0.01$; $\eta^2 = 0.98$; ES large) was found. Additionally, there was a significant condition x time interaction for subjective rating of mental fatigue ($F_{(8, 17)} = 129.80$; $p = 0.01$; $\eta^2 = 0.84$; ES large). There was no significant difference in subjective ratings of mental fatigue between 50CON and 100CON ($p = 0.36$), between 50CON and 200CON ($p = 0.62$), or between 100CON and 200CON ($p = 0.93$). However, the mental fatigue or smartphone app use conditions (50MF, 100MF, and 200MF) demonstrated a significantly higher subjective rating of mental fatigue relative to the no smartphone app use control conditions (50CON, 100CON, and 200CON; $p = 0.01$). There were no significant differences between 50MF, 100MF, and 200MF for subjective rating of mental fatigue ($p = 0.72$).

50, 100, and 200-m freestyle performance

50-m freestyle performance. There was no significant difference between 50CON and 50MF for 50-m freestyle performance (Figure 2A; $F_{(2, 23)} = 0.63$; $p = 0.81$; $\eta^2 = 0.02$; ES trivial).

100-m freestyle performance. There was a significant main effect for both condition 468 ($F_{(2, 23)} = 66.63$; $p = 0.01$; $\eta^2 = 0.73$; ES medium) and time ($F_{(2, 23)} = 6694.17$; $p = 0.01$; $\eta^2 = 1.00$; ES large), and there was also a significant condition x time interaction (Figure 2B; $F_{(4, 21)} = 8.95$; $p = 0.01$; $\eta^2 = 0.27$; ES small) for 100-m freestyle performance. While there was no significant performance difference in the first 50 meters of the 100-m freestyle between 100MF and 100CON conditions (see Figure 3), participants in the 100MF condition demonstrated a significantly lower performance in the second 50 meters relative to those in conditions in the first 50 meters (Figure 3) ($p = 0.91$), the third 50 meters ($p = 0.07$), or the 100CON condition (Figure 3; $p = 0.02$). Overall, participants in the 100MF condition performed more slowly than those in the 100CON condition ($p = .01$).

200-m freestyle performance. There was a significant main effect for both condition ($F_{(2, 23)} = 71.40$; $p = 0.01$; $\eta^2 = 0.77$; ES medium) and time ($F_{(2, 23)} = 6855.07$; $p = 0.001$; $\eta^2 = 1.14$; ES large), and there was also a significant condition x time interaction (Figure 2C; $F_{(4, 21)} = 11.72$; $p = 0.01$; $\eta^2 = 0.42$; ES small) for 200-m freestyle performance. There was no significant difference between performances of participants in 200MF and 200CON conditions in the first 50 meters (Figure 3) ($p = 0.91$), the third 50 meters ($p = 0.07$), or the fourth 50 meters ($p = 0.06$). However, participants in the 200MF condition demonstrated a significantly lower performance in the second 50-meters than those the 200CON condition (Figure 3; $p = 0.01$). There was a significant overall difference between 200MF and 200CON 486 conditions for the 200-m freestyle performance ($p = 0.01$).

*****Figures 2 & 3 insert here*****

*****Figure 3 insert here*****

CMJ

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

HRV indicators

There was a significant main condition effect for R-R interval ($F_{(6, 19)}$ = 62.48; p = 0.01; η^2 = 0.72; ES medium), SDNN ($F_{(6, 19)}$ = 193.44; p = 0.01; η^2 = 0.89; ES large), RMSSD ($F_{(6, 19)}$ = 230.80; p = 0.01; η^2 = 0.90; ES large), and pNN50 ($F_{(6, 19)}$ = 161.93; p = 0.01; η^2 = 0.87; ES large). There was also a main time effect for R-R interval ($F_{(6, 19)}$ = 206.27; p = 0.01; $\eta 2$ = 0.89; ES = large), SDNN ($F_{(6, 19)}$ = 286.80; p = 0.01; $\eta 2$ = 0.92; ES large), RMSSD ($F_{(6, 19)}$ = 438.32; p = 0.01; η^2 = 0.94; ES large), and pNN50 ($F_{(6, 19)}$ = 253.83; p = 0.01; η^2 = 0.92; ES large). There was a significant condition x time interaction for R-R interval ($F_{(6, 19)}$ = 48.74; p = 0.01; η^2 = 0.67; ES medium), SDNN ($F_{(6, 19)}$ = 241.48; p = 0.01; η^2 = 0.91; ES large), RMSSD ($F_{(6, 19)}$ = 238.81; p = 0.01; η^2 = 0.90; ES large), and pNN50 ($F_{(6, 19)}$ = 199.40; p = 0.01; η^2 = 0.89; ES large). For all experimental conditions, we observed decreased values for the R-R interval, SDNN, RMSSD and pNN50 from initial to post-experiment (30-minutes) (p = 0.01). There were significant differences in R-R interval, SDNN, RMSSD, and pNN50 for comparisons of 200 (200MF and 200CON) to 100 (100MF and 100CON) and 50-meters (50MF and 50CON) (p = 0.01). There were also significant differences in R-R interval, SDNN, RMSSD, and pNN50 for comparisons of 100 (100MF and 100CON) to 50-meters (50MF and 50CON) (p = 0.01).

Discussion

The results of this study showed that social media apps on smartphones for prolonged periods (i.e., 30-minutes) caused mental fatigue (i.e., impaired Stroop task response time and increased VAS), while 30-minutes watching videos about Olympic Games on an 84-inch screen caused no changes in mental fatigue indicators (i.e., Stroop task response time and VAS). The main findings showed that mental fatigue impaired performance in 100 and 200-m freestyle without changing the pacing. No impairments for the 50-m freestyle performance in international-level swimmers occurred. So, the hypotheses of the present study were partially supported by the results.

The present investigation indicated that the use of smartphone social media apps (WhatsApp, Instagram, and Facebook) for 30-min attenuates response time in the Stroop task and increases the subjective rating of mental fatigue, supporting other findings (Fortes et al., 2019). The main mechanisms that might explain the mental fatigue are an increase of theta wave in the prefrontal cortex (Franco-Alvarenga et al., 2019), an increase of adenosine concentration in the anterior cingulate cortex (Martin et al., 2018), inhibition of dopamine neurotransmission receptor in the brain (Smith et al., 2018), reduction of brain glycoses (Martin et al., 2018), and attenuation of brain oxygenation (Russel, Jenkins, Smith, Halson, & Kelly, 2019b). Also, scientific evidence shows that the mental fatigue might reduce sports performance (Fortes et al., 2019; Coutinho et al., 2018; Moreira et al., 2018), including in swimming (Penna et al., 2018).

For the 50-m freestyle performance, our results revealed no difference between 50CON and 50MF conditions. Kalva-Filho et al. (2015) found that adenosine triphosphate, muscular glycogen storage, reaction time on the starting block, and muscular strength capacity are determinants for the 50-m freestyle performance. Considering that 50-m freestyle total time in the physical effort is inferior to 30-s in high-level swimmers (McGibson et al., 2018), the task is considered of high intensity and short duration. Some studies also showed no effect of mental fatigue on physical performance in high intensity and short duration (Pageux, Marcora, & Leppers, 2013; Smith, Marcora, & Coutts, 2015). Coutinho et al. (2018), when analyzed soccer players, showed that the acceleration in small-sided games was similar between mental fatigue and control conditions. In the present study, the results for CMJ showed no differences in post-experiment between mental fatigue and control conditions, supporting the scientific literature. It seems that mental fatigue does not affect physical performance in high intensity and short time.

For the 100-m and 200-m freestyle performances, we found an impaired performance following smartphone social media app use (100MF and 200MF) compared to control conditions (100CON and 200CON). The percentage differences between experimental conditions (MF vs. CON) was approximately 2.0%. In professional athletes, this small percentage represents the difference between the winner and fourth place. For example, in the 2019 World Championship, the time difference between the winner (Dressel) and fourth place (Chiereghini) in the 100-m freestyle race was 0.92 s, 1.95% difference (FINA, 2019).

A systematic review with metanalysis showed that mental fatigue impairs physical performance on high-intensity tasks with durations greater than one-minute (McMorris et al., 2018). The psychobiological theory (Marcora et al., 2009) explains the impaired performance in 100 and 200-m freestyle. In a mentally fatigued athlete, the increased perception of effort and lack of energy might impair physical tasks of moderate and long duration, that is, the athlete will reduce speed and intensity to regulate the higher rate of perceived exertion (Franco-Alvarenga et al., 2019; Marcora et al., 2009).

Regarding the participants' pacing (i.e., variant performances in each 50-m segment of the races), performance was similar between participants in mental fatigue conditions (100MF and 200MF) and control conditions (100CON and 200CON). In the 100MF condition, athletes performed the first 50-m adopting the same effort as in the 100CON. However, in the second 50-m, performance was impaired in the mentally fatigued group relative to the control group. For the 200-m, the mentally fatigued participants showed relative difficulty only for the second 50-m. The pacing adopted by athletes in both races (100 and 200-m freestyle) was a positive shape (McGibson et al., 2018). Franco-Alvarenga et al. (2019) revealed reduced performance in the 20-km time trial with trained cyclists in a mental fatigue state, although the authors identified no difference for pacing ("J" shaped). Despite differences in the participants between the present study (using international-level swimming athletes) and other scientific investigations (using athletes of different sports), our results for 100 and 200-m freestyle performances support past scientific literature for pacing.

Concerning HRV indicators (R-R interval, SDNN, RMSSD, and pNN50), we found that, after the race, the HRV indicators were reduced, regardless of the mental fatigue manipulation. There was no effect of mental fatigue on HRV (Fortes et al., 2019; Penna et al., 2018). It seems that the brain areas activated by mental fatigue are different from those activated by the autonomic nervous system. For mental fatigue, the intensity and amplitude of theta wave in the anterior cingulate cortex and prefrontal cortex increase significantly (Franco-Alvarenga et al., 2019; Martin et al., 2018). On the other hand, for HRV, the intensity and amplitude of beta waves in the left insular cortex increase considerably (Okano et al., 2015). Other studies showed that the magnitude of HRV reduction after physical effort relates to the duration or task volume (Nakamura et al., 2015; Vilamitjana et al. 2014), explaining the findings in the present study.

Although the present study presented novel and important findings, some limitations must be mentioned. The 'mental load' during smartphone use was not standardized. Theta wave in the electroencephalogram (EEG), a mental fatigue indicator, was not measured, as well as internal training load (PSE-session method). Also, styles such as 400-m freestyle, 400-m medley, and 200-m butterfly were not measured. In this sense, we recommend that future investigations include EEG to demonstrate mental fatigue via theta band, measures of the internal training load, and other swimming styles in the experiment. Meanwhile, current findings should be considered with caution.

From a practical standpoint, our study demonstrated that prolonged use (more than 30-min) of smartphone social media apps (WhatsApp, Instagram, and Facebook) have a detrimental performance effect and should be forbidden before races for international-level swimming athletes. Also, it is important to determine whether an athlete is mentally fatigued before races (a Stroop task might be performed before races). If so, coaches should define strategies to reduce mental fatigue impairments. The mental fatigue might define a championship winner, mainly in high-performance athletes. Thus, it must be considered an important feature in competitions.

Conclusion

Our results showed that mental fatigue reduced the performance in 100 and 200-m freestyle in international-level swimmers, but the 50-m freestyle performance was not impaired. It seems that the mental fatigue caused by social media apps impairs 100 and 200-

m freestyle performance, but not in physical efforts smaller than 30-s duration as in 50-m freestyle.

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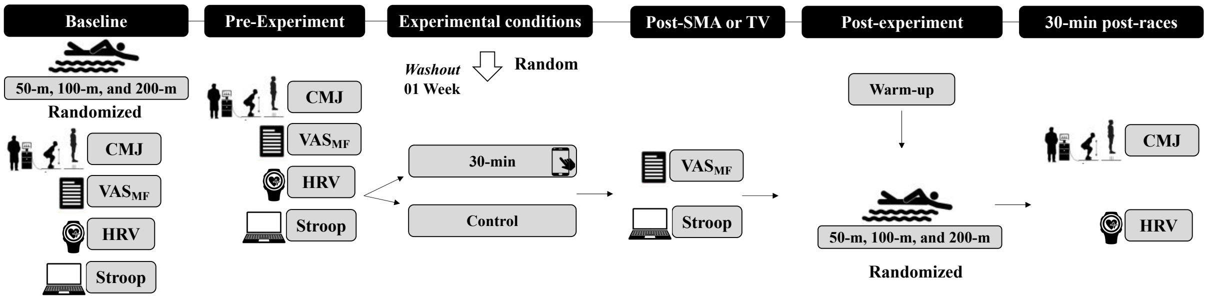
Table 1

Descriptive data of variables in baseline

Variable	Mean	Standard deviation
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

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



558
559 Figure 1
560 *Experimental design of study*
561 *Note.* SMA = smartphone; CMJ = countermovement jump; VAS_{MF} = Mental Fatigue Visual Analogue Scale; HRV = heart
562 rate variability.

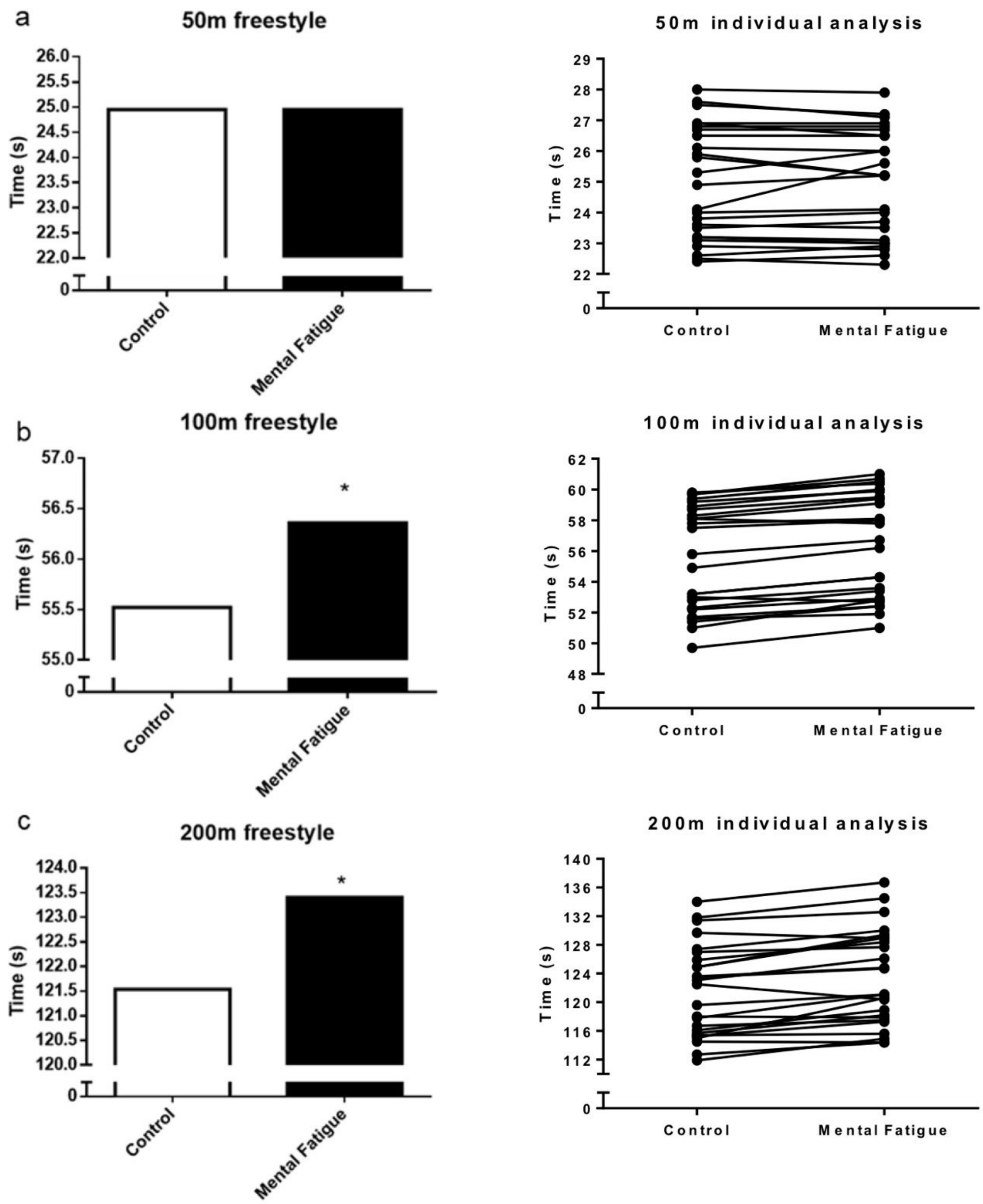


Figure 2

50 (A), 100 (B) and 200-m (C) freestyle performance according to experimental condition (control vs. mental fatigue) in professional swimmers.

Note. *$p<0.05$ to control condition.

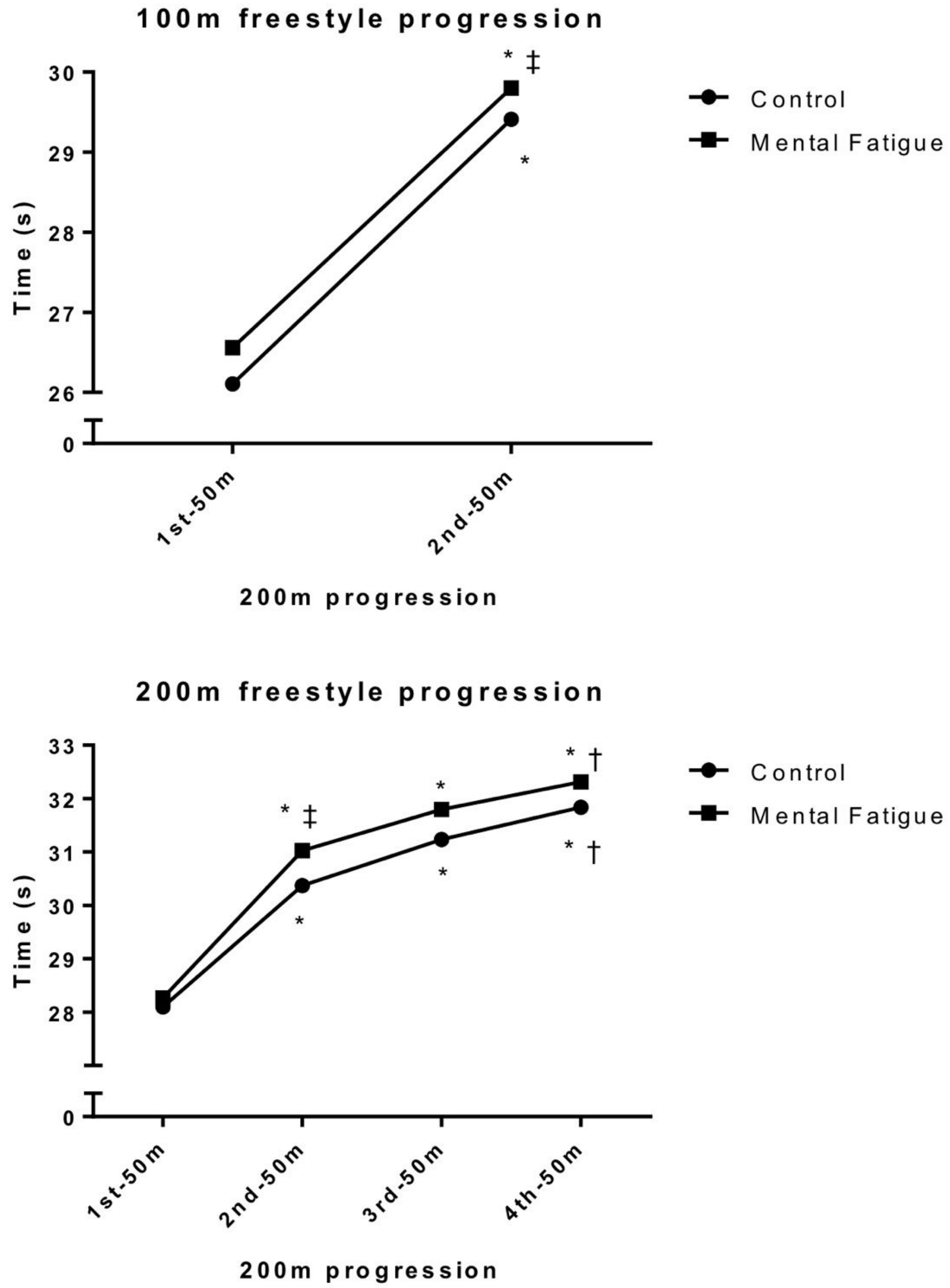


Figure 3

Pacing strategy (every 50-m) for 100 and 200-m freestyle performance in professional swimmers

Note. * = different from 1st-50m; † = different from 2nd-50m; ‡ = different from control.

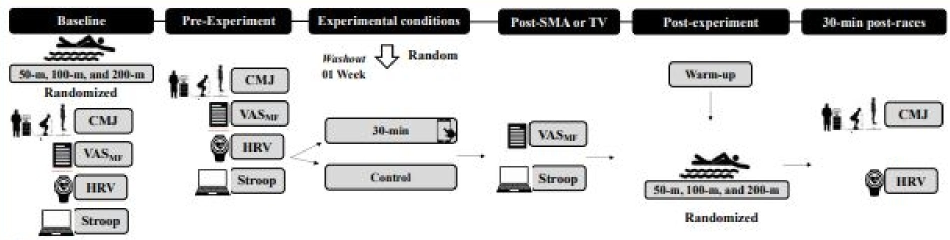


Figure 1

Experimental design of study

Note. SMA = smartphone; CMJ = countermovement jump; VAS_{MF} = Mental Fatigue Visual Analogue Scale; HRV = heart rate variability.

Figure 1

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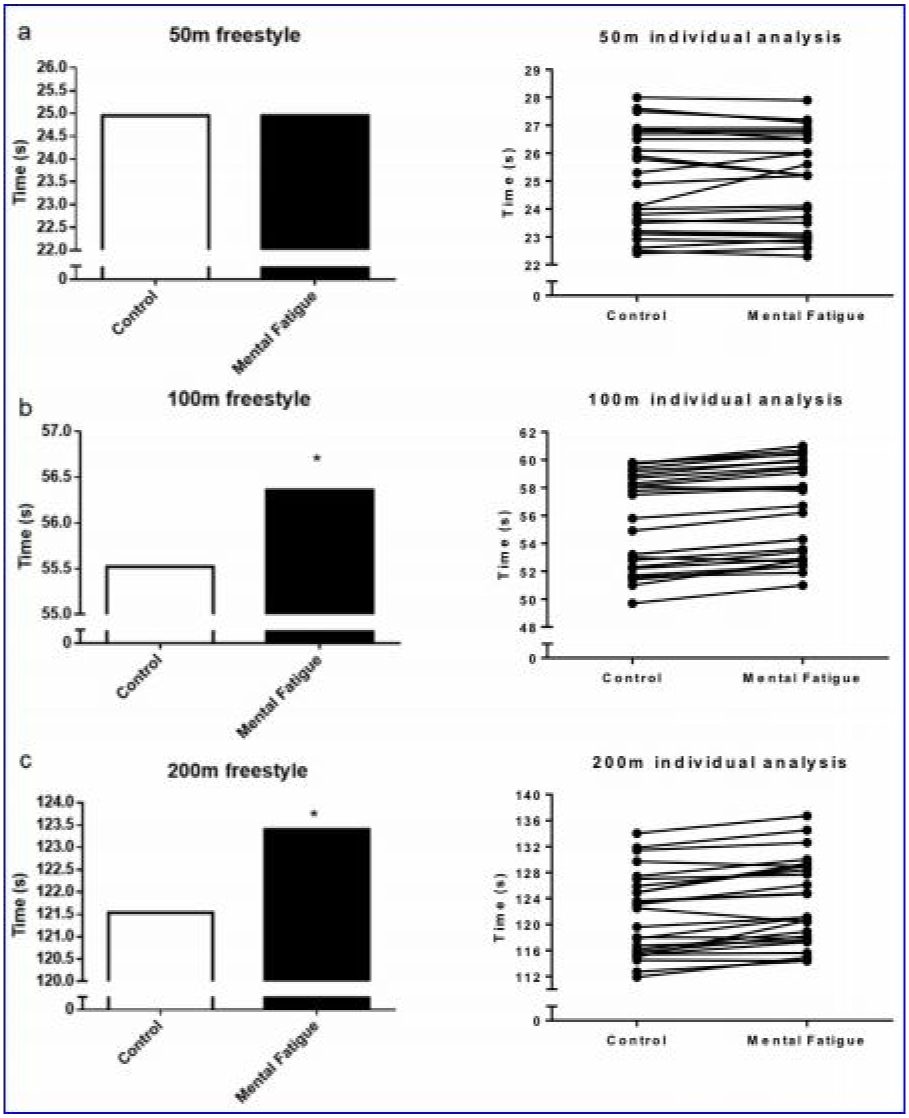

Figure 2

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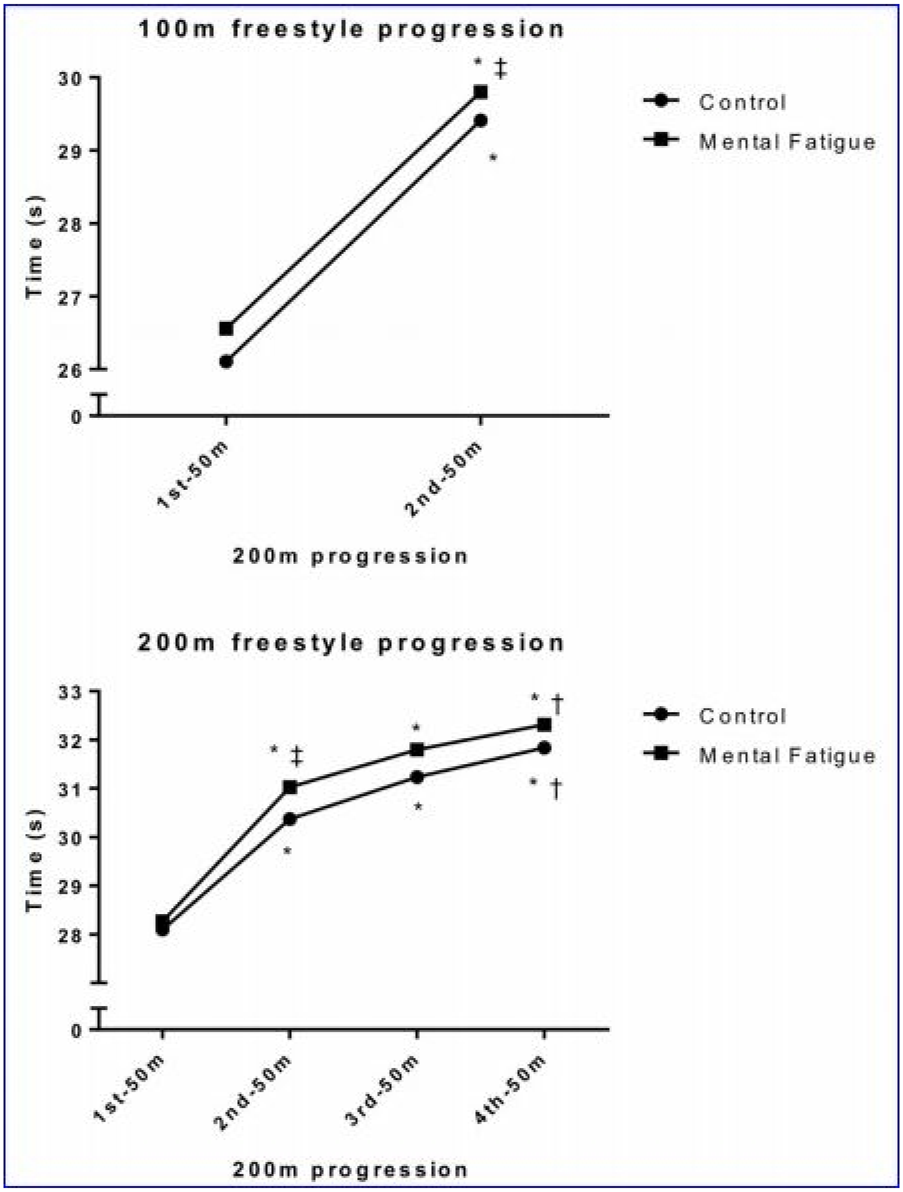

Figure 3

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