

1 **Mental fatigue impairs physical performance in young swimmers.**

2 *Mental fatigue and physical performance in swimmers*

3

4 **Abstract**

5 **Purpose:** This study aimed to investigate the impact of mental fatigue on heart
6 rate variability (HRV), subjective measures of fatigue, and swimming
7 performance in young athletes. **Method:** Sixteen swimmers (15.45 ± 0.51 years
8 old, 7.35 ± 2.20 years of swimming experience) performed a 1500-m time trial on
9 two occasions separated by an interval of at least 72 hours. The 1500-m
10 swimming was preceded by a 30-min treatment that consisted of performing the
11 Stroop Color-Word Test to induce mental fatigue (experimental trial), or watching
12 an emotionally neutral video (control trial). **Results:** Participants reported higher
13 ratings of mental fatigue and mental effort following the Stroop Test when
14 compared to the control trial, but no differences in motivation were observed. The
15 induction of mental fatigue impaired swimming performance, as evidenced by a
16 slower performance (1.2%) to complete the 1500-m swimming trial. No inter-trial
17 differences were identified for Rates of Perceived Exertion during the swimming
18 test or in HRV after the Stroop and swimming tests. **Conclusion:** The results
19 suggest that induction of mental fatigue impairs 1500-m swimming performance
20 without changing HRV.

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22 **Key Words:** Mental Fatigue, Swimming, Heart Rate Variability

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26 INTRODUCTION

27 Mental fatigue is conceptualized as a psychobiological state induced by
28 sustained periods of demanding cognitive activity and characterized by feelings
29 of tiredness and lack of energy (6,19). The adverse effects of mental fatigue on
30 cognitive performance have been extensively reported (33,17), however, its
31 effects on physical performance have only recently been investigated.

32 The empirical evidence gathered to date suggests that mental fatigue does not
33 impair short-duration activities requiring all-out strategies (20). However, mental
34 fatigue has been shown to affect athletic performance in longer-duration activities
35 wherein a continuous regulation of effort is necessary. For instance, previous
36 studies have shown the deleterious effect of a mental fatigue state on running
37 (18,23) and cycling performance (8,19). Similarly, an induced state of mental
38 fatigue has been reported to reduce physical and technical performance in
39 football (27), and to impair the accuracy and speed of football-specific decision-
40 making (29).

41 The observed deleterious effects of mental fatigue on physical performance have
42 been primarily attributed to a higher perception of effort in mentally fatigued
43 athletes, as usually assessed by the Rating of Perceived Exertion (RPE) scale
44 (7). It has been suggested that an increased perception of effort could be linked
45 to an augmented activation of the central motor command (i.e., motor-related
46 cortical activity) and its inherent corollary discharges (10). Indeed, when two
47 identical exercises are compared, the individuals subjected to a mental fatigue
48 condition (i.e., experimental condition) show a higher perception of effort
49 compared to a control, despite the absence of other differences in myriad

50 physiological measures (e.g., heart rate, blood lactate concentrations, oxygen
51 consumption) (18,19,28).

52 Although impaired physical performance during a mental fatigue state appears to
53 occur without concomitant changes in physiological parameters, some studies
54 have revealed that mental fatigue can influence the autonomic regulation of the
55 heart rate (21,30), as evaluated non-invasively through heart rate variability
56 (HRV) analysis. HRV can be defined as over-time variation of consecutive heart
57 beats and is thought to reflect the autonomic nervous system regulation of the
58 heart rate (1). In mental fatigue states, the altered autonomic regulation is
59 characterized by increases in the low-to-high frequency ratio (LF/HF), which
60 indicates that mental fatigue induces sympathetic hyperactivity and decreases
61 parasympathetic activity. In a sporting context, a positive relationship has been
62 identified between rest, increased HF, and improved performance in swimmers
63 (2,9), thus highlighting the importance of verifying possible changes in HRV in
64 mentally fatigued swimmers.

65 To date, however, no research has examined the effects of mental fatigue in
66 swimmers, who are regularly exposed to long distance training sessions (24)
67 after, for example, school classes (cognitively demanding activity). Moreover, the
68 evaluation of a possible influence of mental fatigue on post-exercise HRV is
69 important because sympathetic hyperactivity and parasympathetic underactivity
70 may lead to poor recovery after a training stimulus (4,22). In turn, this imbalance
71 between stimulus and recovery can lead to unhealthy syndromes such as
72 overtraining and burnout (16).

73 Therefore, the purposes of this investigation were to (a) examine the effects of
74 an induced state of mental fatigue on 1500-m swimming performance, and (b)
75 identify possible alterations in the autonomic control of HR following a prolonged
76 mental exertion task. We hypothesized that mental fatigue would impair
77 swimming performance, while leading to an increased perception of effort and
78 lower values of HRV.

79 **METHODS**

80 *Participants*

81 Sixteen swimmers (11 boys and 5 girls, age 15.45 ± 0.51 years, 7.35 ± 2.2 years
82 of swimming experience) participated in this randomized cross-over investigation.
83 All participants attended school for at least 5 hours per day, were competing in
84 state or national competitions, and trained an average of 30,000 m per week at
85 the time of the study. Participants and their parents signed an informed consent
86 form outlining potential risks and the study procedures, which were approved by
87 the University's Ethical Advisory Committee (project number
88 55286716.0.0000.5149).

89 *Experimental Overview*

90 All participants were instructed to maintain their regular sleep patterns and
91 habitual consumption of caffeine (to avoid a confounding effect due to
92 abstinence). They were also instructed to avoid any vigorous exercise and to take
93 a regular meal at least 24 hours and 2 hours before the two trial sessions. All data
94 collection procedures occurred in the same period of the day and were matched
95 to the athletes' training schedule. The same athlete was always tested at the
96 same time of day. The trial sessions were separated by an interval of at least 72h.

97 Upon arrival for the trials, participants received a standard explanation of the
98 procedures, including instructions for the use of the 6-20 RPE scale (7), and were
99 instructed to drink 500 mL of water. Participants were directed to a quiet room
100 where they completed the visual analogue scales (VAS) for the assessment of
101 mental fatigue (3,20), which was followed by a control or mentally fatiguing
102 treatment. Immediately following the treatment, mental fatigue, mental effort and
103 motivation were assessed using VAS, and heart rate was recorded for 5 min.
104 Participants were then directed to the swimming pool to perform the 1500-m
105 swimming trial. After the swimming trial, the participants were immediately
106 conducted to an isolated, quiet room where they remained seated for 10 minutes.
107 Mental fatigue and mental effort data were gathered and after the initial 5 minutes,
108 their heart rate was recorded. These time intervals were standardized and tightly
109 controlled.

110 *Treatment*

111 Mental fatigue was induced by a 30-min paper version of a modified Stroop Test.
112 This test has been used in recent studies involving mental fatigue in sporting
113 contexts (27,28). The test required participants to respond verbally to the color of
114 words (red, blue, green and yellow) printed in a random order. The correct answer
115 corresponded to the ink color of the word. For instance, if the ink color of the word
116 was red, the correct answer was the meaning of the word rather than its color.
117 Verbal responses were monitored by a member of the research team, and for
118 each error, the participants were instructed to restart the current line of words.
119 Participants were instructed to respond correctly to as many words as possible
120 for a period of 30 min.

121 The control trial involved watching a 30-min video regarding the history of world
122 aviation. This video was identified as emotionally neutral (no change in HR, HRV,
123 or mood) in a pilot test.

124 *Subjective Ratings*

125 To serve as manipulation checks, subjective ratings of mental fatigue, mental
126 effort and motivation were recorded using a 100-mm VAS anchored by the words
127 “not at all” and “maximal”; this scale has been previously used in mental fatigue
128 studies (27,28). Ratings of mental fatigue were measured at pre-treatment (PRE-
129 TREAT), post-treatment (POST-TREAT) and post-swimming (POST-SWIM).
130 Mental effort was measured at POST-TREAT and POST-SWIM. Motivation was
131 measured only at POST-TREAT and referred to the upcoming 1500-m trial. The
132 VAS was recently used in studies to measure subjective ratings of mental fatigue,
133 mental effort and motivation in sport and exercise context (19,20,29). To analyze
134 the three scales, a ruler was used to measure the distance between the initial
135 mark and the point marked by the participant. Scores were reported as arbitrary
136 units (AU).

137 *HRV*

138 HRV was measured at two moments (POST-TREAT and POST-SWIM) in both
139 conditions. For all measurements, the participants remained seated for five
140 minutes, with a normal breathing rate, in silence and with no body movements.

141 To collect the heart rate data, a chest strap (Polar® H7, Kempele, Finland)
142 connected to a recording watch (Polar® V800) was used to continuously record
143 R-R intervals (31). These data were transferred to a Polar software (Polar®
144 ProTrainer) and exported for subsequent analysis using the Kubios HRV version

145 2.0, which was developed by the Biosignal Analysis and Medical Imaging Group
146 at the Department of Applied Physics, University of Kuopio, Finland.

147 The data were visually inspected to identify ectopic beats and artifacts (which did
148 not exceed 3% of the recorded data) and those identified were manually removed
149 and replaced by interpolation of their respective adjacent R-R intervals.

150 To identify the HRV in the time-domain, average R-R intervals (RR mean) and
151 the root mean square of successive differences between adjacent R-R intervals
152 (RMSSD) were analyzed. A fast Fourier transform of the RR signals was used for
153 analyzing HRV in the frequency-domain. The spectral response provided by the
154 analysis was divided into three bands: very low frequency (VLF; 0.003 to 0.04
155 Hz), low-frequency (LF; 0.04 - 0.15 Hz) and high frequency (HF; 0.15 to 0.40 Hz).

156 *Performance Measures*

157 The participants were instructed to swim 1500-m as fast as possible. Data
158 collection was conducted by the same two researchers. One researcher was
159 responsible for recording the pace of each 50-m lap and the time elapsed until
160 finishing the time trial, while the other researcher was responsible for recording
161 the RPE every 300 m. The RPE scale was printed on a 1 m x 0.9 m banner that
162 was placed beside the pool in a spot perfectly visible to the participants (all trials
163 happened in lanes 1 or 8).

164 *Statistical Analysis*

165 Data were initially tested for normality (Shapiro-Wilk test) and homogeneity
166 (Levene test). Because all the data collected passed these two initial tests,
167 parametric tests were performed thereafter. A paired Student *t*-test was

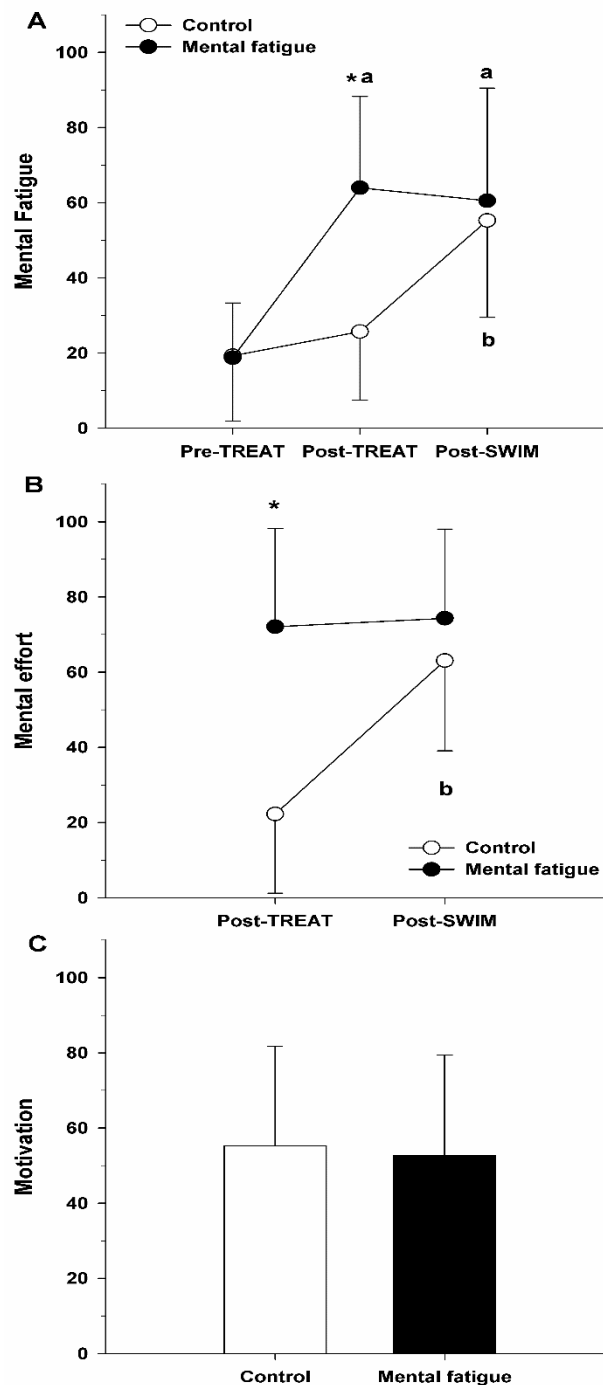
168 performed to compare mean data (collected at a single point) between
169 experimental trials. Two-way ANOVAs with repeated measures were used to
170 compare data between experimental trials over distance for different moments
171 (PRE-TREAT, POST-TREAT and POST-SWIM), followed by the Tukey's *post*
172 *hoc* test whenever applicable. Additionally, Cohen *d* magnitude effect-size (ES)
173 was calculated to assess the magnitude of the difference between the
174 experimental trials. ES was calculated through mean differences and was
175 considered trivial (ES < 0.2), small (ES 0.2 – 0.6), medium (ES 0.6 – 1.2) and
176 large (ES ≥ 1.2) (13). All results are presented as the mean ± standard deviation.
177 The significance level was set at $p \leq 0.05$. All analyses were performed in the
178 Sigma Plot 11 statistical package.

179 **RESULTS**

180 *Perceptual Measures*

181 The subjective perception of mental fatigue was influenced by the moment of
182 analysis and experimental condition. Indeed, a two-way ANOVA revealed a
183 significant interaction between these two factors ($F = 9.06$; $p < 0.001$; power =
184 0.95). At PRE-TREAT, prior to the Stroop Test or control manipulation, no inter-
185 trial differences were observed ($p = 0.94$; ES = 0.03). As expected, perception of
186 mental fatigue increased after the application of the Stroop Test ($p < 0.001$; ES =
187 2.32), but did not change for the control treatment ($p = 0.61$; ES = 0.13). Also, the
188 perception of mental fatigue was greater after the Stroop Test than control
189 treatment ($p < 0.001$; ES = 1.80). In contrast, perception of mental fatigue
190 increased at POST-SWIM relative to POST-TREAT in the control trial ($p < 0.01$;
191 ES = 1.34), but did not differ following exercise in the mental fatigue trial ($p =$
192 0.96; ES = 0.19) (Figure 1-A).

193 After the Stroop Test, mental effort was higher than the control treatment ($p <$
 194 0.001 ; $ES = 2.11$). In contrast, mental effort after exercise was not different
 195 between trials ($p > 0.05$; $ES = 0.47$) (Figure 1-B). When measured at POST-
 196 TREAT, before the swimming time-trial, motivation was not different between
 197 trials ($p = 0.54$; $power = 0.05$; $ES = 0.09$) (Figure 1-C).



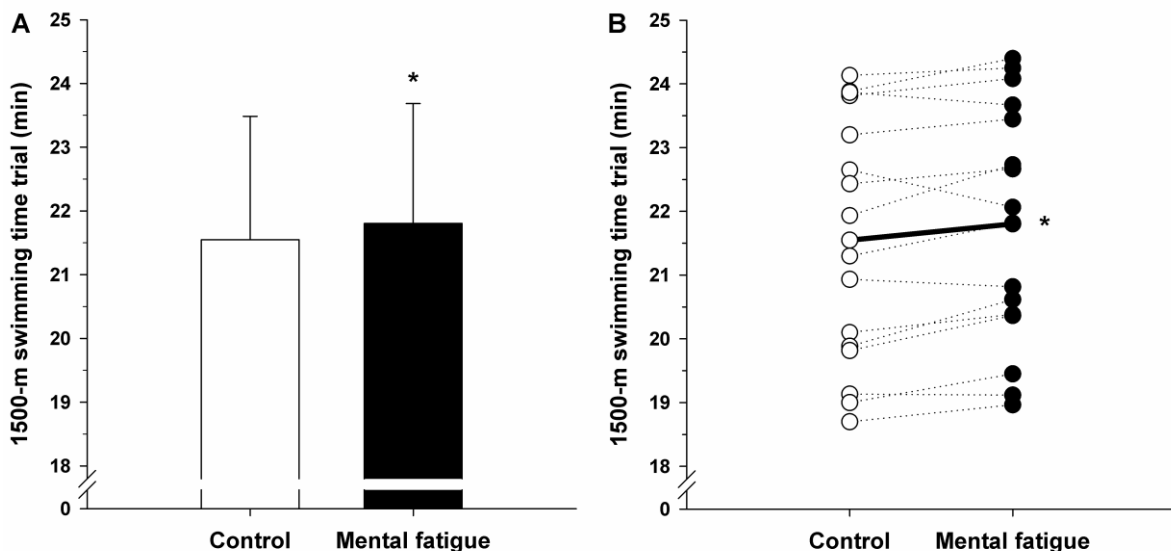
199 Figure 1. Subjective measure of mental fatigue (A) before treatment (PRE-TREAT), after
 200 the Stroop test or control manipulation (POST-TREAT) and at post-swimming (POST-
 201 SWIM). Mental effort (B) after the Stroop test or control manipulation (POST-TREAT)
 202 and at post-swimming (Post-SWIM). Motivation (C) before the swimming time trial at both
 203 trials.

204 * significantly different ($p < 0.05$) from the control trial; a significantly different ($p < 0.05$)
 205 from the previous moment in the mental fatigue trials; b significantly different ($p < 0.05$)
 206 from the previous moment in the control trial.

207

208 *Swimming Performance*

209 Mental fatigue reduced 1500-m swimming performance, as evidenced by the 1.2
 210 \pm 1.3% increase in the time spent to complete the 1500-m time-trial ($p < 0.05$;
 211 power = 0.70; ES = 0.13) (Figure 2A). Of note, 12 of the 16 swimmers took longer
 212 to complete the 1500-m after being subjected to the Stroop Test (Figure 2B).
 213 Therefore, mean speed attained by the swimmers was slower in the trial when
 214 they were mentally fatigued than during the control trial (1.169 ± 0.106 m/s vs.
 215 1.155 ± 0.101 m/s; $p < 0.05$; power = 0.74; ES = 0.14).

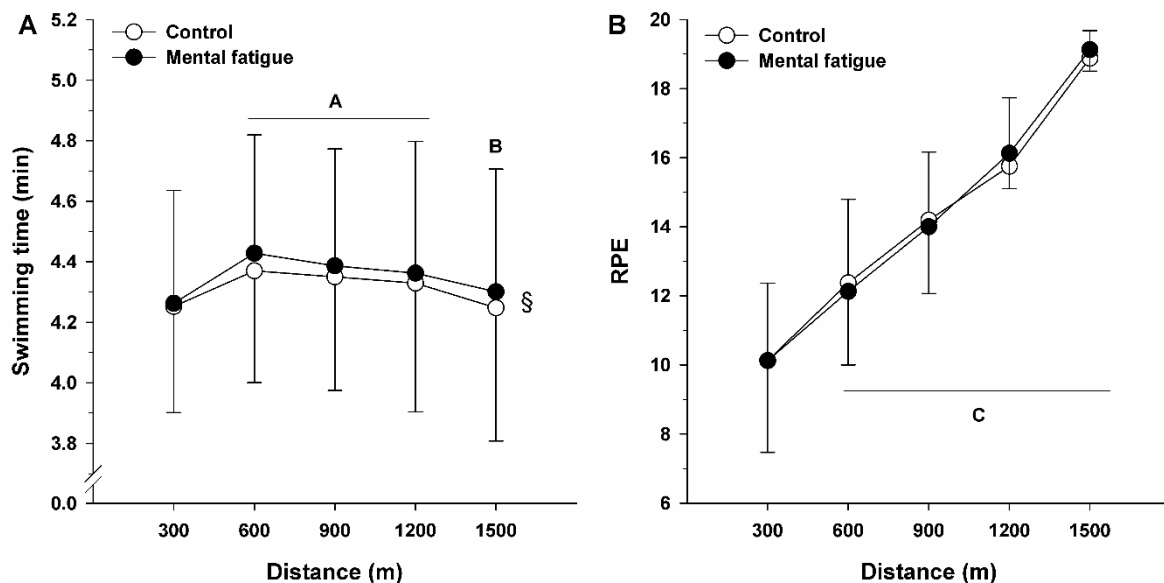


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217 Figure 2. Mean total exercise time (A) and individual times (B) to complete the 1500-m
 218 swimming time-trial at the two experimental trials (i.e., control and mental fatigue trials).
 219 Each dotted line represents a volunteer, whereas a solid line represents their mean
 220 response.

221 * significantly different ($p < 0.05$) from the control trial.

222 Swimming pacing profile was influenced by the distance travelled ($F = 20.01$; $p <$
 223 0.001 ; power = 1.00), with swimmers being slower at 600 m ($p < 0.001$; ES =
 224 0.39), 900 m ($p < 0.001$; ES = 0.30) and 1200 m ($p = 0.01$; ES = 0.23) when
 225 compared to 300 m; and being faster at 1500-m when compared to 600 m ($p <$
 226 0.001 ; ES = 0.32) and 900 m ($p < 0.01$; ES = 0.24). In addition, pacing mean time
 227 for each 300 m was slower during the mental fatigue trial relative to the control
 228 trial ($F = 4.62$; $p < 0.05$; power = 0.42; ES = 0.10). Regarding the perceptual
 229 response, RPE increased over time ($F = 126.25$; $p > 0.001$; power = 1.00) (Figure
 230 3-B), reaching values close to 20 at the end of the trial. Despite the differences in
 231 performance, RPE was not different between experimental trials ($F = 0.01$; $p >$
 232 0.05 ; power = 0.05; ES = 0.01).



233

234 Figure 3. Pacing (A) and rate of perceived exertion (B) during the 1500-m swimming
 235 time-trial at both experimental trials.

236 § significant effect of condition ($p < 0.05$); A significantly different ($p < 0.05$) from the 300
 237 m; B significantly different from the 900 m; C significantly different from the previous
 238 distance.

239

240 *HRV*

241

242 The two-way ANOVA revealed only a main effect for the moment of analysis in
243 the data regarding RR mean ($F = 15.49$; $p < 0.001$; power = 1.00), RMSSD ($F =$
244 44.95 ; $p < 0.001$; power = 1.00) and LF/HF ($F = 9.98$; $p = 0.009$; power = 0.79).
245 No main effect for experimental trials or interaction between factors were
246 observed. The post hoc tests showed that RR mean ($p < 0.001$; ES = 3.98) and
247 RMSSD ($p < 0.001$; ES = 2.49) were lower at POST-SWIM compared to POST-
248 TREAT, and that LF/HF was higher at POST-SWIM compared to POST-TREAT
249 ($p < 0.001$; ES = 1.13). No differences in the natural logarithm of low frequency
250 ($F = 0.02$; $p = 0.91$; power = 0.05; ES = 0.03), LF ($F = 0.08$; $p = 0.79$; power = 0.05;
251 ES = 0.06), natural logarithm of high frequency ($F = 0.11$; $p = 0.74$; power = 0.05;
252 ES = 0.07) and HF ($F = 0.07$; $p = 0.80$; power = 0.05; ES = 0.05) were observed
253 across trials or conditions (Table 1).

254 *** TABLE 1 HERE ***

255

256 **DISCUSSION**

257

258 The aim of the present study was to test the hypothesis that a prolonged and
259 demanding cognitive test would lead to a higher perception of mental fatigue
260 state, which in turn would impair swimming performance and alter autonomic
261 cardiac balance. Our findings partially confirmed this hypothesis. Indeed, a
262 prolonged cognitive test was found to increase perception of mental fatigue and
263 impair swimming performance (Figure 2), without concomitant changes in the
264 cardiac autonomic balance of the heart (Table 1). These findings corroborate
265 previous studies that investigated the relationship between mental fatigue status
266 and physical performance (8,18,28). Specifically, previous work in this area has
267 revealed that mental fatigue impairs running performance (18,27). However, to

268 the best of our knowledge, this is the first study assessing the effects of a mental
269 fatigue on swimming performance.

270 Noteworthy, the statically significant effect of mental fatigue manipulation on
271 swimming performance (i.e., $0.2 \pm 1.3\%$ increase in mean time to complete a
272 1,500-m time-trial) was trivial for both swimming time (ES = 0.13) and mean speed
273 (ES = 0.14). However, 12 of the 16 swimmers (75%) reduced their physical
274 performance after the mental fatigue manipulation and a delta of 1.2% in the total
275 exercise time is greater, for example, than the differences found between the
276 three medalists in the 2016 Olympic Games 1500-m swimming (delta of 0.72%
277 in time to complete the 1500-m of swimming). Thus, the small effects of mental
278 fatigue on physical performance and mean speed could be relevant for a
279 competitive environment.

280 Even though mental fatigue impaired physical performance, as evidenced by
281 reduced swimming speed (Figure 2), no changes in RPE were observed
282 throughout the 1500-m swimming test (Figure 3). This aligns with the results of
283 other studies (18,28) who observed no between-condition differences in RPE
284 during freely-paced running protocols. Collectively, these results suggest that
285 mental fatigue increases perceived exertion during both fixed and freely-paced
286 endurance exercise. Indeed, during fixed-pace exercise, athletes report higher
287 RPE, whereas during freely-paced exercise athletes regulate their pace to
288 maintain similar RPE between conditions.

289 It has been suggested that changes in motivation status, due to mental fatigue,
290 may influence physical performance. However, we did not find this to be the case,
291 considering that no inter-trial differences were identified in motivation levels prior
292 to swimming (Figure 1C). Thus, the impaired physical performance after the

293 application of the Stroop Test cannot be explained by changes in motivation. In
294 fact, it was shown that mental fatigue is not always associated with task
295 disengagement (12) or reduced motivation (20). Mental fatigue has been rather
296 associated with decreases in other components of cognitive performance, such
297 as cognitive efficiency (measured by impaired reaction time in a prolonged flanker
298 test) (5,17) or availability of cognitive resources (15). Of note, the influence of the
299 aforementioned components of cognition on physical performance are currently
300 unknown.

301 The perception of mental effort increased in the control trial, while remained high
302 in the mental fatigue trial (Figure 1B). Collectively, these results reflect the fact
303 that long-distance swimming was perceived as mentally effortful (in both trials),
304 and this effort may be associated with the continuous conscious decision-making
305 regarding the regulation of exercise intensity (25). This result aligns with the
306 premise that when a participant engages in long-duration and/or high intensity
307 exercise, their attentional focus remains internal (associative) (14), as particularly
308 related to the regulation of bodily sensations and pacing strategy (32).

309 The induction of higher perceptions of mental fatigue did not change any HRV
310 parameter investigated in the present study (Table 1). Thus, the hypothesis that
311 mental fatigue reduces the vagal activity and promotes sympathetic hyperactivity
312 was not confirmed. As such, changes in HRV cannot be attributed to any acute
313 physical impairment caused by mental fatigue. This result contrasts with those
314 previously reported (21,30), whose studies showed reduced HRV and increase
315 in sympathetic markers (e.g. Low frequency component) due to mental fatigue.
316 These conflicting findings may have occurred because we examined HRV after
317 the cognitive test, whereas (21,30) examined HRV during the cognitive test. This

318 methodological difference is important as the predominance of vagal tone could
319 be quickly recovered after the termination of the cognitive task (26), thus not
320 being captured after the conclusion of the physical effort.

321 **PRACTICAL APPLICATIONS**

322 Previous studies have shown that mental fatigue impairs physical performance in
323 a variety of sporting contexts. This investigation extends these findings to the
324 context of long distance (1500-m) swimming. The findings of this study are
325 important for coaches and professionals who are responsible for the planning and
326 executing of training programs, particularly those involving young, school-aged
327 athletes. Youth athletes are engaged, on a daily basis, in extensive cognitive
328 tasks (e.g., school) in addition to their training and competition routine. Coaches
329 should be conscious of the impact that these demanding cognitive tasks may
330 have on performance during training sessions. For example, compared to a
331 regular week of class, mental fatigue may be higher during an exam week at
332 school, thus negatively impacting athletic performance. Another important
333 question regarding the swimming context in general and mental fatigue in
334 particular, pertains to the culture of early morning training sessions. Chronic
335 reduced sleep time can negatively influence performance in both cognitive and
336 motor tasks (11). Furthermore, leisure activities involving virtual environments
337 (e.g., electronic games, social media) are very popular among school age
338 populations. These activities may potentially induce mental fatigue.

339 **CONCLUSION**

340 The present data demonstrates that induction of mental fatigue slightly impaired
341 physical performance in young swimmers. Notably, during the mental fatigue

342 trials, the young athletes presented a similar RPE, but swam at a slower pace
343 than in the control trial. No changes in HRV were observed between conditions.

344

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458 TABLE 1 – Heart rate variability parameters calculated before and after the 1,500
 459 m- swimming in the two experimental conditions (mental fatigue and control).

460

	Mental fatigue		Control	
	POST-TREAT	POST-SWIM	POST-TREAT	POST-SWIM
RR (ms)	772.4 ± 99.8	529.5 ± 46.7	783.7 ± 79.8	522.2 ± 28.4
RMSSD (ms)	50.7 ± 23.1	13.5 ± 10.0	46.3 ± 14.3	14.6 ± 9.6
InLF (ms ²)	-2.59 ± 0.24	-2.63 ± 0.32	-2.65 ± 0.33	-2.59 ± 0.28
InHF (ms ²)	-1.66 ± 0.19	-1.61 ± 0.32	-1.61 ± 0.18	-1.62 ± 0.32
LF (n.u.)	74.7 ± 12.5	81.0 ± 16.3	71.9 ± 13.1	82.3 ± 11.2
HF (n.u.)	25.1 ± 12.4	18.8 ± 16.2	27.9 ± 13.1	17.4 ± 11.1
LF/HF	3.8 ± 1.9	8.4 ± 6.3	3.3 ± 1.8	6.7 ± 3.6

461 Caption: InHF = Natural Logarithms of High Frequency; InLF = Natural
 462 Logarithms of Low Frequency; HF = High Frequency; LF = Low Frequency;
 463 LF/HF = Ratio; POST-SWIM = Post Swimming; POST-TREAT = Post Treatment;
 464 RMSSD = Square root of the mean of the sum of the squares of differences; RR
 465 = R-R intervals

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