Residual Effects of Mental Fatigue on Subjective Fatigue, Reaction Time and Cardiac Responses

Adalberto Ferreira Junior[1], Priscila Chierotti[2], Juliano M. Gabardo[3], Bruno Giovanini[4], Alexandre H. Okano[5], Cosme F. Buzzachera[6], Victor H. A. Okazaki[7], Nilo M. Okuno[8] and Leandro R. Altimari[9]

Abstract

This study investigated the residual effects of mental fatigue induced by the 30-minute incongruent Stroop Color Word task on subjectively perceived fatigue, reaction time, and heart rate variability (HRV) in 20 adult volunteers (10 men; 10 women). Dependent variables were assessed before, immediately after, and at 15, 30, 45, and 60 minutes after two conditions: (a) a 30-minute incongruent Stroop Color Word task (mental fatigue condition); or (b) a 30-minute control condition. At pre-testing, there were no significant differences between experimental conditions for any variable. However, there was a residual effect of mental fatigue on psychological responses for up to ~15 minutes after the experimental manipulation ($p < 0.01$). For the reaction time task, significant differences were observed only immediately after the mental fatigue, compared to the control condition ($p < 0.0001$). There were no significant differences between experimental conditions for any parameters of HRV at any testing period. In addition, there were no significant gender related differences at any period or in either condition for any variable. The data suggest that mental fatigue can alter psychological responses for up to ~15 min after its induction, and mental fatigue may impair cognitive reaction time performance without changing autonomic cardiac responses.

Keywords: Cognitive fatigue; cognitive exertion; exertion psychological; cardiac autonomic activity.

Mental fatigue (MF) is caused by prolonged cognitive activity and promotes a decrease in motivation and alertness, as well as an increase in feelings of tiredness or a lack of energy (Gergelyfi, Jacob, Olivier, & Zénon, 2015). It has been shown that MF impairs cognitive function and plays an important role in increasing error risk in the workplace (Sadeghniiat-Haghighi & Yazdi, 2015). In addition, MF is known to be detrimental factor to performance of different tasks (Tanaka, Ishii, & Watanabe, 2015), by altering the amount of physical effort people are willing to invest in an exercise workout (Brown & Bray, 2019) and exercise performance (MacMahon, Schücker, Hagemann, & Strauss, 2014; Martin, Meeusen, Thompson, Keegan, & Rattray, 2018).

The impairment in cognitive performance from MF is correlated with brain over-activation (Tanaka et al., 2015). In addition, the increase in reaction time and number of errors after MF is associated with a reduction in the involvement of prefrontal cognitive control processes (Budini, Lowery, Durbaba, & De Vito, 2014; Lorist et al., 2000). Moreover, impairment in performance in endurance exercises is related to higher perceived exertion (Marcora, Staiano, & Manning, 2009).

In relation to heart rate variability (HRV), Tanaka, Mizuno, Tajima, Sasabe, & Watanabe (2009) demonstrated decreased vagal nerve activity and increased sympathetic nerve activity during the 2-back test over a 30 minute period as a means of inducing MF. Mizuno et al. (2011) showed sympathetic hyperactivity and decreased parasympathetic activity after MF, caused by a prolonged mental load. It is believed that maintenance of cognitive task performance requires an increase in the contribution of motivation or mental effort, and this increases sympathetic activity (Ishii, Tanaka, & Watanabe, 2014). Moreover, the decrease in

1 Department of Physical Education, Universidade Estadual de Londrina (UEL), PR, Brazil

2 Department of Physical Education, Universidade Estadual de Londrina (UEL), PR, Brazil.

3 Department of Physical Education, Universidade Estadual de Londrina (UEL), PR, Brazil.

4 Department of Physical Education, Universidade Estadual de Londrina (UEL), PR, Brazil.

5 Universidade Federal do ABC. Center of Mathematics, Computing, and Cognition. São Bernardo do Campos, São Paulo, Brazil.

6 Department of Public Health, Experimental and Forensic Medicine - University of Pavia, Pavia, Italy.

7 Department of Physical Education, Universidade Estadual de Londrina (UEL), PR, Brazil.

8 Department of Physical Education, Universidade Estadual de Ponta Grossa (UEPG), PR, Brazil.

9 Department of Physical Education, Universidade Estadual de Londrina (UEL), PR, Brazil. Corresponding author: Leandro Ricardo Altimari, Department of Physical Education, Universidade Estadual de Londrina (UEL). Rodovia Celso Garcia Cid, Pr 445 Km 380, Campus Universitário, Londrina, PR, Brazil, Zip code: 86057-970, Brazil, Tel: +55 (43) 3371-5953, E-mail: adalbertojr07@hotmail.com

parasympathetic activity seems to be a characteristic feature of central nervous system fatigue (Tanaka et al., 2009).

In order to induce MF, studies have used different tasks that require significant cortically mediated cognitive effort, the most commonly employed tasks having been the Stroop Color Word Task (Pageaux, Marcora, Rozand, & Lepers, 2015), the AX-continuous performance test (MacMahon et al., 2014; Marcora et al., 2009), and the switch task paradigm (Budini et al., 2014). Additionally, across this research, studies have varied length of time each used to induce MF in the application of tasks, including, for example, protocol variations between 22 and 30 minutes of the Stroop Color Word Task (Bray, Graham, Martin Ginis, & Hicks, 2012; Pageaux et al., 2015; Salam, Marcora, & Hopker, 2018), 90 minutes of the AX-continuous performance test (MacMahon et al., 2014; Marcora et al., 2009), and 100 minutes of the switch task paradigm (Budini et al., 2014; Lorist et al., 2000). Although some studies were characterized by experimental conditions performed immediately after MF induction, to our knowledge no studies investigated the longer residual effects of MF manipulations on psychological responses, reaction time, and autonomic cardiac responses. Therefore, the present study aimed to analyze the residual effect of mental fatigue induced by the 30-minute incongruent Stroop Color Word task on these variables. In particular, we hypothesized that (i) psychophysiological measurements would be modified until 30 min after the mental fatigue protocol, (ii) MF would increase reaction time, and (iii) MF would impair cardiac autonomic responses.

Method

Participants

Twenty adult volunteers (10 men: age = 25.5 ± 7.9 years; height = 174.0 ± 3.7 centimeters; weight = 78.7, ± 11.3 kilograms; and 10 women: age = 25.7 ± 4.2 years; height = 164.1 ± 3.6 centimeters; weight = 58.9 ± 4.1 kilograms) took part in this study. Participants were recruited by word of mouth. The inclusion criteria for participant acceptance into the study were: (a) aged between 18-35 years, (b) absence of any kind of cardiovascular or metabolic disease, and (c) no use of any medication that could influence cardiovascular and psychological responses. The Local Ethics Committee approved this study in accordance with international standards. All participants provided written informed consent following a provision to them of explicit written instructions describing the procedures related to the study. All participants, however, were naive to the study's aims and hypotheses.

Study protocol

We performed data collection on three consecutive days. On the first day, we took anthropometric measurements and familiarized the participants with the procedures. On remaining days, the participants returned to the laboratory and engaged in experimental sessions of (a) mental fatigue (MF) and (b) control condition (CO) on separate days with randomized order.

During MF e CO condition, we collected baseline measurements for all dependent variables on all participants while they remained seated on a comfortable chair. We used the first ten minutes to identify psychological variables, have them perform the reaction time task, and gather HRV baseline values. Next, they engaged in the thirty minutes of either the MF or CO condition. We then reassessed participants on the psychological variables, reaction time task, and HRV immediately after the 30-minute condition (MF or CO) and for every fifteen minutes afterward for a period of one hour (i.e., 15, 30, 45, and 60 minutes). The subjects were instructed not to ingest alcohol or caffeinated beverages and not to perform vigorous physical activity for 24 hours prior to data collection. All sessions were conducted in the same period of the day, aiming to avoid circadian effects on the measures.

Experimental Conditions

The MF condition consisted of 30 minutes engagement in a modified incongruent version of the Stroop Color Word task. Four words (yellow, blue, green, red) were serially presented on a computer screen until the participant validated an answer, with intervals between word presentations of and were ~1500 milliseconds after the participant response. Participants were instructed to press one of four colored buttons on the keyboard (yellow, blue, green, red) with the correct response being the button corresponding to the ink color (either yellow, blue, green, red) of the word presented on the screen. The software displayed the different stimuli randomly on the screen such that, for example, if the word on the screen was "green" but the ink used for this word was blue, the correct answer was blue. To avoid participants losing attentional focus on the word cues, we presented conflicting information such that, when the word was presented in black ink, participants were to select the button corresponding to the word color written. For example, if the stimulus showed the word "yellow" in black ink, participants were required to press the yellow button. Feedback was presented on the screen after each selection to inform the participants of whether they had given an incorrect or correct answer, and to inform them as to the speed of their response. We used the Stroop Color Word Task Software v.1.0 (Okazaki, 2010a) to develop the task, and analyze the Stroop reaction time and accuracy scores. The number of stimuli provided to the subjects during the Stroop task averaged 354.75 ± 60.67, the average reaction time was 848.64 ± 211.9 milliseconds, and the percentage of wrong responses was 4.38 ± 3.91. In the CO condition, participants were asked to remain seated, receiving no stimuli throughout the procedure. Both protocols had the same duration, and participants were not allowed to talk to the research team so as to avoid any dissociative thoughts or interference. The HRV response was measured throughout both the MF and CO conditions.

Measurements

Subjective Fatigue

To measure participants' psychological reactions to these experimental manipulations, participants were asked to rate their mental fatigue by responding to "how do you feel right now?" before, immediately after, and each 15 minute post- experimental time period for one hour (i.e., at 15, 30, 45, and 60 minutes following the MF or CO condition). The volunteers responded on a 10-point scale, ranging from 1 = "not al all" to 10 = "extremely" (Salam et al., 2018).

In addition, we used the Brunel Mood Scale (BRUMS) to quantify the current mood of participants before, immediately after, and for four 15 minutes periods (15, 30, 45, and 60 minutes) after the experimental conditions (Terry, Lane, & Fogarty, 2003). This questionnaire contains six subscales (anger, confusion, depression, fatigue, tension, and vigor), with each subscale containing four items. The participants answered a numerical rating ranging from 0 = "not at all" to 4 = "extremely" to describe each of these mood subscales, and the sum of their responses on each subscale yielded a total score ranging from 0 to 16 for each participant at each testing period.

Reaction Time Task

The reaction time task was performed using the Software Reaction Time Task v.2.0 (Okazaki, 2010b). In the reaction time task (this dependent measure was independent from the Stroop Color Word task reaction time), participants were required to rest their index finger (right hand) on the letter H of a keyboard and to respond as quickly as possible to five imperative random stimuli. The stimulus consisted on the appearance of the letter H (in black with a blue circle around) on a white monitor. The mean of the five stimuli was calculated before, immediately after, and for 15 minutes periods (15, 30, 45, and 60 minutes) following the experimental condition.

Heart Rate Variability (HRV)

We recorded the participants' R-R intervals using a portable cardiac monitor (V800; Kempele, Finland) at rest, during the experimental conditions, and during the recovery period after the experimental conditions. Ectopic beats were visually identified and manually replaced from the tachogram with interpolated adjacent R-R interval values. All participants remained in a chair for 100 minutes (rest: 10 minutes; during experimental conditions: 30 minutes; and recovery period: 60 minutes). During rest, the experimental sessions, and recovery period (10-15 minutes, 25-30 minutes, 40-45 and 55-60 minutes) the final five minutes were used to analyze the time domain and frequency domain of HRV through Fast Fourier Transform (FFT), using Kubios HRV software (version 3.1.0). For the variables verified in the frequency domain were verified in normalized units, the high frequency (HF 5 – 10 minutes - 0.15-0.50 Hz) and low frequency (LF 5 – 10 minutes - 0.04-0.15 Hz) components were verified in normalized units.

Statistical analysis

Data are presented as arithmetic means and standard deviations. The Gaussian distribution was observed through the Shapiro-Wilk test of normality. Data were analyzed using a two-way repeated measures ANOVA (condition x trial). When significant differences were found, we used the LSD post-hoc test to discriminate when there were significant differences. Statistical significance was set at $p < 0.05$. We analyzed data using *Statistica* 10.0.

Results

Mental Fatigue Scale and BRUMS Fatigue Rating

The subjective fatigue perceptions (Mental Fatigue Scale and BRUMS Fatigue Rating), assessed before, immediately after, and at 15, 30, 45, and 60 minutes for both condition (MF and CO) are shown in Figure 1.

At pre-condition there was no significant differences on subjective fatigue perceptions between experimental conditions (Figure 1). However, only for the MF condition, significant differences were found between the pre-condition values and values at all other time sampling points on subjective fatigue perceptions ($p < 0.01$). Significant differences were observed immediately after the experimental conditions, and at 15 and 30 minutes afterwards between the MF and CO conditions for all participants for mental fatigue scale ($p < 0.0001$) (Figure 1A), whereas in BRUMS fatigue rating significant differences were observed immediately after the experimental conditions and at 15 minutes afterwards between the MF and CO ($p < 0.0001$) (Figure 1B). Comparing men and women, there were no significant differences in any condition or period.

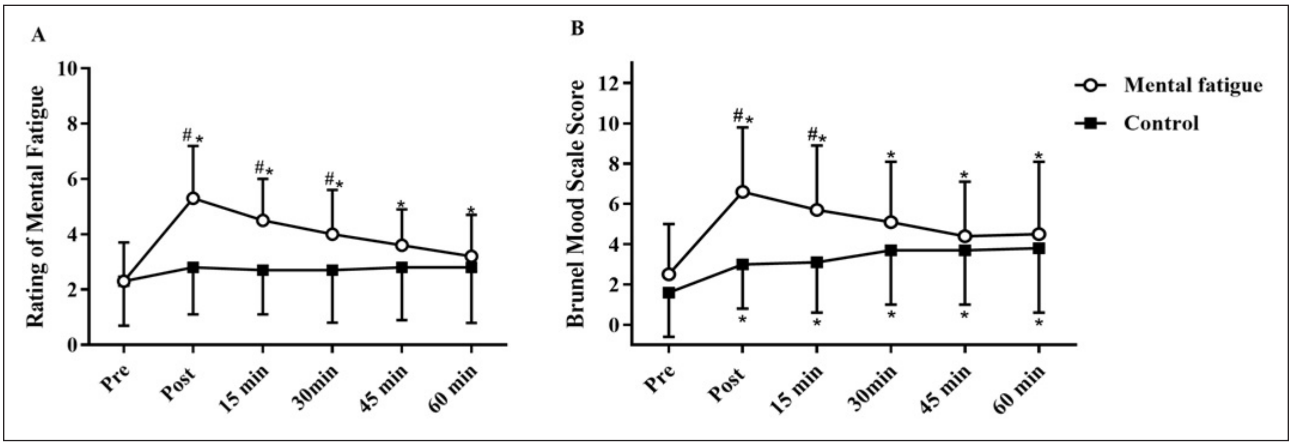

Figure 1. Mean ± SD of Scale of Mental Fatigue (A) and fatigue subscale of the BRUMS (B) before (Pre), immediately after, (Post), and each 15 min after the experimental condition (15, 30, 45, and 60 min). * Significantly different from before experimental condition ($p < .05$). # Significantly different from control condition at the same period ($p < .05$)

Reaction Time

In relation to the reaction time task, there were no significant differences between experimental conditions at the pre-condition testing period. However, only in the MF condition, there was a significant difference for the reaction time task immediately after the condition compared to pre-condition testing ($p < 0.0001$). In addition, there were significant differences between the MF and CO conditions immediately after the conditions ($p < 0.0001$) (Figure 2). Additionally, there were no significant reaction time differences between men and women as a function of conditions or testing periods.

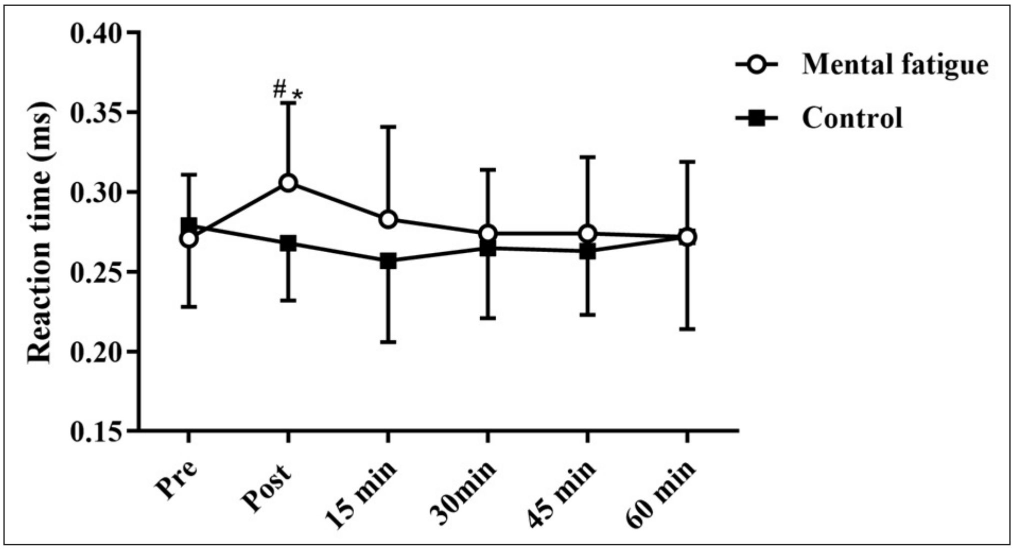

Figure 2. Mean ± SD of reaction time task before, immediately after, and each 15 min after the experimental condition (15, 30, 45, and 60 min). * Significantly different from before experimental condition ($p < .05$). # Significantly different from control condition at the same period ($p < 0.05$).

HRV

At pre-condition testing, there were no significant differences between MF and CO conditions for any parameters of the HRV, and, even at other testing periods, we found no significant HRV differences between experimental MF and CO conditions (Table 1). There were significant differences between HRV tests at the pre-condition period and other periods in both experimental conditions ($p < 0.05$) (Table 1).

Table 1
Mean ± SD of HRV at rest, during the five final minutes (25-30th min) of the experimental condition (POST), and each 15 min after the experimental condition (10-15th, 25-30th, 40-45th and 55-60th).

	PRE	POST	15	30	45	60
All (n = 20)						
Time domain						
R-R mean (ms)						
CON	803 ± 142	836 ± 135*	839 ± 139*	836 ± 135*	845 ± 144*	857 ± 135*
MF	794 ± 144	799 ± 134	822 ± 139*	841 ± 139*	840 ± 148*	850 ± 151*
HR (bpm)						
CON	76.8 ± 12.3	73.3 ± 10.8*	73.1 ± 10.4*	72.7 ± 10.9*	72.8 ± 10.8*	71.3 ± 9.9*
MF	77.5 ± 11.8	76.7 ± 10.6	74.7 ± 10.9*	72.9 ± 10.2*	73.2 ± 11.25*	72.4 ± 11.3*
RMSSD (ms)						
CON	37.5 ± 12.3	43.6 ± 15.8*	41.9 ± 12.9*	42.9 ± 14.9*	44.1 ± 12.5*	47.1 ± 13.1*
MF	38.3 ± 16.7	38.1 ± 15.8	45.7 ± 17.8*	45.2 ± 17.5*	44.7 ± 13.57*	47.7 ± 15.4*
Frequency domain						
lnLF (ms^2)						
CON	7.1 ± 0.6	7.3 ± 0.6	7.1 ± 0.6	7.3 ± 0.6	7.5 ± 0.7*	7.5 ± 0.7*
MF	6.91 ± 0.7	7.2 ± 0.7	7.5 ± 0.6*	7.4 ± 0.6*	7.5 ± 0.5*	7.3 ± 0.9*
lnHF (ms^2)						
CON	6.3 ± 0.7	6.5 ± 0.8	6.4 ± 0.7	6.4 ± 0.7	6.6 ± 0.6	6.6 ± 0.6
MF	6.1 ± 1.1	6.3 ± 0.9	6.6 ± 0.9*	6.6 ± 0.9*	6.6 ± 0.7*	6.6 ± 0.6*

*Note. CON = control condition; MF = mental fatigue condition. * Significantly different from before experimental condition ($p < 0.05$).*

Discussion

The purpose of this study was to verify the residual effects of mental fatigue on subjective fatigue perceptions, reaction time, and autonomic cardiac responses. The main results of this study were that 30 minutes of an incongruent Stroop Color Word task lead residual effects on participants' perceived fatigue responses up to ~15 minutes after mental fatigue induction when compared with the control condition. Furthermore, there was an increase in reaction time immediately after (but not at later times after) the MF compared to the control condition. There were no HRV changes following MF induction.

The present study is the first to demonstrate that 30 minutes of an MF inducing task (incongruent Stroop task) altered the perceived fatigue for up to ~15 min after the induction. The participants' reports of mental fatigue on the Mental Fatigue Scale increased after the MF induction and remained higher for up to 30 minutes later when compared with the control condition. Salam et al. (2018) and Silva-Cavalcante et al. (2018) found similar results using the Mental Fatigue Scale when comparing pre- and immediately post- MF induction participant responses. In addition, we employed the fatigue subscale of the BRUMS as a subjective marker of mental fatigue and found greater BRUMS fatigue reports up to 15 minutes after MF induction when compared with the control condition. Some other studies have verified similar changes on the BRUMS fatigue subscale immediately after an MF protocol, corroborating with our results, as scores on the fatigue subscale increased immediately after an AX-CPT MF protocol with a 90 minute duration (MacMahon et al., 2014; Pageaux, Marcora, & Lepers, 2013; Smith, Marcora, & Coutts, 2015) and after 30 minutes of the incongruent Stroop Color Word task (Pageaux et al., 2015). However, Rozand, Pageaux, Marcora, Papaxanthis, & Lepers (2014) and Pires et al. (2018) did not find significant differences in their fatigue subscale after participants were engaged in an MF protocol. These different results may be due to differences in the experimental protocols, and some participants may be less prone to protocol-induced MF. In relation to study differences in the residual effect of perceived fatigue on these scales, we believe that the fatigue sub-scale of the BRUMS may have inherent variability because it contained four items. It was not possible to compare our results of residual effects on this subjectively experienced fatigue variable with other studies, as we did not find other studies containing these data.

Many potential factors can contribute to mental fatigue following mental exertion, and the neuromodulator adenosine is a promising candidate, as its concentration increases during mental exertion (Martin et al., 2018). Adenosine is known to accumulate in some brain regions during periods of wakefulness, effortful cognitive activity, and intense physical exercise (Dworak, Diel, Voss, Hollmann, & Strüder, 2007; Martin et al., 2018). Adenosine actions play an important role in the anterior cingulate cortex, and various different tasks that require significant cognitive effort, such as the AX-CPT test and Stroop Color Word task are associated with both activity in the anterior cingulate cortex and the induction of MF (Swick & Jovanovic, 2002). This brain region is involved in such different mental processes as emotional processing and control, self-regulation, and effort/reward processing, among others (Martin et al., 2018). Thus, during prolonged cognitive demand of this type (Stroop task), an increase in local adenosine concentration could alter mental processes and be associated with an increased sense of mental fatigue, as we found.

Our results demonstrated an impairment in reaction time performance immediately after MF (but not later). Similarly, MF has been found by others to promote an additional cognitive control mechanism related to impairments on a self-regulation task (Lorist et al., 2000; Pageaux et al., 2015). Gergelyfi et al. (2015) found opposite results in which participants presented slower reaction time after an MF protocol even with decreased motivation, but, in this study, unlike ours, rewards were offered for the best performances. Thus, methodological differences between studies helps account for conflicting findings. For example, our failure to find a residual effect of MF on the reaction time task may be due to the short period of induction of MF and/or our use of a different simple reaction time task.

Acute mental workload activates two systems: mental facilitation and inhibition. The balance between these systems determines whether performance is impaired, maintained, or improved (Ishii et al., 2014). MF is caused by repeated and prolonged mental workload, causing impaired energy metabolism or oxidative damage, promoting dysfunction in the facilitation system and over-activation of the inhibition system through central sensitization or classic conditioning, thus promoting impairment in performance (Ishii et al., 2014). These mechanisms may have contributed to our results.

The MF induced by 30 minutes of the Stroop task did not negatively alter any HRV measure in this study at any testing period. Thus, we could not confirm our hypothesis that mental fatigue would impair autonomic cardiac autonomic responses. This result contrasts with Tanaka et al. (2009) and Mizuno et al. (2011) who demonstrated increased sympathetic and decreased parasympathetic activity after MF induction. However, our results corroborate Penna et al. (2018) who found no differences in HRV parameters between MF and control conditions using the same protocol for MF induction as in the present study. In addition, Hoshikawa & Yamamoto (1997) found no differences in HRV indices after MF, but showed differences in other hemodynamic parameters. Thus, it is possible that HRV might not be sensitive enough to reflect alterations in cardiac responses in the autonomic nervous system during and after MF (Hoshikawa & Yamamoto, 1997). Additionally, these conflicting findings may have occurred due to the different experimental protocols used.

Among the limitations of the present study was our failure to measure brain activity, utilize other cognitive tasks, and employ other physiological parameters (e.g., hemodynamic and vascular parameters) that might help us better understand and explain the effects of mental fatigue on psychophysiological responses. Additionally, we utilized a very small number of participants for these analyses, meaning that we may have lacked the statistical power to detect small effect size differences and our findings may have limited generalizability to other populations. Despite this, the present study helps to increase understanding of the effects of mental fatigue.

Conclusions

The current data indicate that mental fatigue alters the psychological responses even ~15 min after its induction. In the reaction time task, there was impairment in performance only immediately after mental fatigue induction. In relation to cardiac autonomic responses there were no changes at any time after induction of mental fatigue. Therefore, based on these results, it could be suggested that 30 min of mental fatigue induction can alter psychological responses for ~15 min after induction. Thus, performance of cognitive tasks requiring sustained attention should be avoided prior to tasks that require good performance (i.e., endurance exercise). Future research is needed to examine the mechanisms responsible for these changes in psychophysiological responses and to verify if different induction times can increase the effect of mental fatigue and have longer residual effects.

Acknowledgments

The authors thank the volunteers who contributed their time and energy to participate in this study. The authors also thank CAPES for providing scholarships to the students.

Efectos residuales de la fatiga mental en la fatiga subjetiva, tiempo de reacción y respuestas cardíacas

Resumen

Este estudio investigó los efectos residuales de la fatiga mental inducidos por 30 minutos Test de Stroop con palabra con color incongruente sobre la fatiga percibida subjetivamente, el tiempo de reacción y la variabilidad de la frecuencia cardíaca (HRV) en 20 voluntarios adultos (10 hombres, 10 mujeres). Las variables dependientes se evaluaron antes, inmediatamente después y a los 15, 30, 45 y 60 minutos después de dos condiciones: (a) Test de Stroop con palabra con color incongruente de 30 minutos (condición de fatiga mental); o (b) condición de control de 30 minutos. En la pre condiciones, no hubo diferencias significativas entre las condiciones experimentales para ninguna variable. Sin embargo, hubo un efecto residual de la fatiga mental en las respuestas psicológicas durante hasta ~ 15 minutos después de la manipulación experimental ($p < 0{,}01$). Para la tarea de tiempo de reacción, se observaron diferencias significativas solo inmediatamente después de la fatiga mental, en comparación con la condición de control ($p < 0{,}0001$). No hubo diferencias significativas entre las condiciones experimentales para ningún parámetro de HRV en ningún período. Además, no hubo diferencias significativas relacionadas con el género en ningún período ni en ninguna de las condiciones para ninguna variable. Los datos sugieren que la fatiga mental puede alterar las respuestas psicológicas hasta ~ 15 min después de su inducción, y la fatiga mental puede afectar el rendimiento del tiempo de reacción cognitiva sin cambiar las respuestas cardíacas autónomas.

Palabras clave: fatiga cognitiva; esfuerzo cognitivo; esfuerzo psicológico Actividad autonómica cardíaca.

Efeitos residuais da fadiga mental na fadiga subjetiva, tempo de reação e respostas cardíacas

Resumo

Este estudo investigou os efeitos residuais da fadiga mental induzida por 30 minutos do teste de Stroop com a palavra de cor incongruente na fadiga percebida de maneira subjetiva, tempo de reação e variabilidade da frequência cardíaca (VFC) em 20 voluntários adultos (10 homens; 10 mulheres). As variáveis dependentes foram avaliadas antes, imediatamente após e aos 15, 30, 45 e 60 minutos após duas condições: (a) teste de Stroop com a palavra de cor incongruente de 30 minutos (condição fadiga mental); ou (b) uma condição controle de 30 minutos. No pré-teste, não houve diferenças significativas entre as condições experimentais para qualquer variável. No entanto, houve um efeito residual da fadiga mental nas respostas psicológicas por até ~ 15 minutos após a manipulação experimental ($p <0{,}01$). Para o teste de tempo de reação, foram observadas diferenças significativas apenas imediatamente após a fadiga mental, em comparação com a condição controle ($p <0{,}0001$). Não houve diferenças significativas entre as condições experimentais para quaisquer parâmetros da VFC em qualquer período. Além disso, não houve diferenças significativas relacionadas ao gênero em qualquer período ou em qualquer condição para qualquer variável. Os dados sugerem que a fadiga mental pode alterar as respostas psicológicas por até 15 minutos após sua indução, e a fadiga mental pode prejudicar o desempenho cognitivo pela piora tempo de reação sem alterar as respostas autonômicas cardíacas.

Palavras-chave: fadiga cognitiva; esforço cognitivo; esforço psicológico; atividade autonômica cardíaca.

References

Bray, S. R., Graham, J. D., Martin Ginis, K. A., & Hicks, A. L. (2012). Cognitive task performance causes impaired maximum force production in human hand flexor muscles. Biological Psychology, 89(1), 195–200. https://doi.org/10.1016/j.biopsycho.2011.10.008

Brown, D. M. Y., & Bray, S. R. (2019). Effects of Mental Fatigue on Exercise Intentions and Behavior. Annals of Behavioral Medicine, 53(5), 405–414. https://doi.org/10.1093/abm/kay052

Budini, F., Lowery, M., Durbaba, R., & De Vito, G. (2014). Effect of mental fatigue on induced tremor in human knee extensors. Journal of Electromyography and Kinesiology, 24(3), 412–418. https://doi.org/10.1016/j.jelekin.2014.02.003

Dworak, M., Diel, P., Voss, S., Hollmann, W., & Strüder, H. K. (2007). Intense exercise increases adenosine concentrations in rat brain: Implications for a homeostatic sleep drive. Neuroscience, 150(4), 789–795. https://doi.org/10.1016/j.neuroscience.2007.09.062

Gergelyfi, M., Jacob, B., Olivier, E., & Zénon, A. (2015). Dissociation between mental fatigue and motivational state during prolonged mental activity. Frontiers in Behavioral Neuroscience, 9(July), 1–15. https://doi.org/10.3389/fnbeh.2015.00176

Hoshikawa, Y., & Yamamoto, Y. (1997). Effects of Stroop color-word conflict test on the autonomic nervous system responses. American Journal of Physiology - Heart and Circulatory Physiology, 272(3 (Part 2)), H1113-1121. https://doi.org/10.1152/ajpheart.1997.272.3.h1113

Ishii, A., Tanaka, M., & Watanabe, Y. (2014). Neural mechanisms of mental fatigue. Reviews in the Neurosciences, 25(4), 469–479. https://doi.org/10.1515/revneuro-2014-0028

Lorist, M. M., Klein, M., Nieuwenhuis, S., De Jong, R., Mulder, G., & Meijman, T. F. (2000). Mental fatigue and task control: Planning and preparation. Psychophysiology, 37(5), 614–625. https://doi.org/10.1017/S004857720099005X

MacMahon, C., Schücker, L., Hagemann, N., & Strauss, B. (2014). Cognitive fatigue effects on physical performance during running. Journal of Sport and Exercise Psychology, 36(4), 375–381. https://doi.org/10.1123/jsep.2013-0249

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

Martin, K., Meeusen, R., Thompson, K. G., Keegan, R., & Rattray, B. (2018). Mental Fatigue Impairs Endurance Performance: A Physiological Explanation. Sports Medicine, 48(9), 2041–2051. https://doi.org/10.1007/s40279-018-0946-9

Mizuno, K., Tanaka, M., Yamaguti, K., Kajimoto, O., Kuratsune, H., & Watanabe, Y. (2011). Mental fatigue caused by prolonged cognitive load associated with sympathetic hyperactivity. Behavioral and Brain Functions, 7(17), 1–7. https://doi.org/10.1186/1744-9081-7-17

Okazaki, V. H. A. (2010a). Stroop Task (Version 2.0) [Computer software]. Retrieved from https://okazaki.webs.com/softwaresdownloads.htm

Okazaki, V. H. A. (2010b). Reaction Time Task (Version.1.0) [Computer software]. Retrieved from https://okazaki.webs.com/softwares-downloads.htm

Pageaux, B., Marcora, S. M., & Lepers, R. (2013). Prolonged mental exertion does not alter neuromuscular function of the knee extensors. Medicine and Science in Sports and Exercise, 45(12), 2254–2264. https://doi.org/10.1249/MSS.0b013e31829b504a

Pageaux, B., Marcora, S. M., Rozand, V., & Lepers, R. (2015). Mental fatigue induced by prolonged self-regulation does not exacerbate central fatigue during subsequent whole-body endurance exercise. Frontiers in Human Neuroscience, 6(67), 1–12. https://doi.org/10.3389/fnhum.2015.00067

Penna, E. M., Filho, E., Wanner, S. P., Campos, B. T., Quinan, G. R., Mendes, T. T., … Prado, L. S. (2018). Mental fatigue impairs physical performance in young swimmers. Pediatric Exercise Science, 30(2), 208–215. https://doi.org/10.1123/pes.2017-0128

Pires, F. O., Silva-Júnior, F. L., Brietzke, C., Franco-Alvarenga, P. E., Pinheiro, F. A., de França, N. M., … Santos, T. M. (2018). Mental fatigue alters cortical activation and psychological responses, impairing performance in a distance-based cycling trial. Frontiers in Physiology, 9(277), 1–9. https://doi.org/10.3389/fphys.2018.00227

Rozand, V., Pageaux, B., Marcora, S. M., Papaxanthis, C., & Lepers, R. (2014). Does mental exertion alter maximal muscle activation? Frontiers in Human Neuroscience, 8(755), 1–10. https://doi.org/10.3389/fnhum.2014.00755

Sadeghniiat-Haghighi, K., & Yazdi, Z. (2015). Fatigue management in the workplace. Industrial Psychiatry Journal, 24(1), 1–12. https://doi.org/10.4103/0972-6748.160915

Salam, H., Marcora, S. M., & Hopker, J. G. (2018). The effect of mental fatigue on critical power during cycling exercise. European Journal of Applied Physiology, 118(1), 85–92. https://doi.org/10.1007/s00421-017-3747-1

Silva-Cavalcante, M. D., Couto, P. G., Azevedo, R. de A., Silva, R. G., Coelho, D. B., Lima-Silva, A. E., & Bertuzzi, R. (2018). Mental fatigue does not alter performance or neuromuscular fatigue development during self-paced exercise in recreationally trained cyclists. European Journal of Applied Physiology, 118(11), 2477–2487. https://doi.org/10.1007/s00421-018-3974-0

Smith, M. R., Marcora, S. M., & Coutts, A. J. (2015). Mental fatigue impairs intermittent running performance. Medicine and Science in Sports and Exercise, 47(8), 1682–1690. https://doi.org/10.1249/MSS.0000000000000592

Swick, D., & Jovanovic, J. (2002). Anterior cingulate cortex and the Stroop task: Neuropsychological evidence for topographic specificity. Neuropsychologia, 40(8), 1240–1253. https://doi.org/10.1016/S0028-3932(01)00226-3

Tanaka, M., Ishii, A., & Watanabe, Y. (2015). Effects of Mental Fatigue on Brain Activity and Cognitive Performance: A Magnetoencephalography Study. Anatomy & Physiology: Current Research, 5(s4), 1–5. https://doi.org/10.4172/2161-0940.s4-002

Tanaka, M., Mizuno, K., Tajima, S., Sasabe, T., & Watanabe, Y. (2009). Central nervous system fatigue alters autonomic nerve activity. Life Sciences, 84(7–8), 235–239. https://doi.org/10.1016/j.lfs.2008.12.004

Terry, P. C., Lane, A. M., & Fogarty, G. J. (2003). Construct validity of the Profile of Mood States - Adolescents for use with adults. Psychology of Sport and Exercise, 4(2), 125–139. https://doi.org/10.1016/S1469-0292(01)00035-8