The Effect of Mental Fatigue on Half-Marathon Performance: a Pragmatic Trial

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Research Article

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Abstract

Purpose It is well established that mental fatigue impairs performance during lab-based endurance tests lasting < 45 min. However, the effects of mental fatigue on longer-duration endurance events and in field settings are unknown. The aim of this study was to investigate the effect of mental fatigue on performance during a half-marathon race.

Methods Forty-six male amateur runners (means ± SD: age 43.8 ± 8.6 years, $\dot{V}O_{2max}$ 46.0 ± 4.1 ml/kg/min) completed an half-marathon after being randomly allocated to performing a 50-min mentally-fatiguing task (mental fatigue group) or reading magazines for 50 min (control group). Running speed, heart rate, and perceived effort were measured during the race.

Results The mental fatigue group completed the half-marathon approximately four minutes slower (106.2 ± 12.4 min) than the control group (102.4 ± 10.2 min), but this difference was not statistically significant (Cohen's $d = 0.333$; $p = 0.265$). However, equivalence was not established ($t(40.88) = 0.239$, $p = 0.594$) and equivalence testing analysis excluded a worthwhile positive effect of mental fatigue on half-marathon performance.

Conclusion Due to its posttest-only design and the achievable sample size, the study did not have enough power to provide evidence that the observed 4-minute increase in half-marathon time is statistically significant. However, equivalence testing suggests that mental fatigue has no beneficial effects on half-marathon performance in male amateur runners, and harmful effects cannot be excluded. Overall, it seems prudent for endurance athletes to avoid mentally-fatiguing tasks before competitions.

Introduction

Mental fatigue is defined as a psychobiological state caused by prolonged cognitive exertion that can impair cognitive performance and/or induce feelings of tiredness and lack of energy (Boksem and Tops 2008). Over the past decade, several experimental studies have shown that mental fatigue can also impair endurance (aerobic) performance in physically active, healthy adults in normal ambient conditions (Marcora et al. 2009; Pageaux et al. 2013, 2014; Brownsberger et al. 2013; MacMahon et al. 2014; Martin et al. 2015; Van Cutsem et al. 2017). In the studies conducted so far, endurance performance was measured with time to exhaustion tests or time trials (Pageaux and Lepers 2016) lasting between 3 and 45 minutes (Van Cutsem et al. 2017). Furthermore, these experiments have been conducted in standardised environments, such as laboratories (Marcora et al. 2009; Pageaux et al. 2013, 2014; Brownsberger et al. 2013; Martin et al. 2015, 2016; Van Cutsem et al. 2017) and an indoor track (MacMahon et al. 2014).

To the best of our knowledge there is no published study about the effects of mental fatigue in outdoor settings and during mass-start competitions lasting more than 45 minutes (long-term endurance performance). This is not surprising because, due to logistics and testing difficulties, it is extremely difficult to conduct randomised controlled studies during real endurance competitions. Indeed, only a handful of such pragmatic trials have been published (Utter et al. 2002; Hansen et al. 2014; Del Coso et al. 2016; Rowlands and Houltham 2017; McCormick et al. 2018; Pugh et al. 2019).

In order to have a more ecologically valid insight of the effect of mental fatigue on endurance performance, the main aim of the current between-subject, posttest-only, randomized controlled study was to test the hypothesis that a mentally-fatiguing task reduces performance during a subsequent official half-marathon race in amateur runners. It is important to underline that a more powerful pretest-posttest design was not feasible for our experiment due to logistical constraints. Therefore, because of the sample size achievable over three editions of the race, statistical power was low for the small-to-moderate effect size we expected based on our previous studies and the results of a recent meta-analysis (Hedge's g = 0.26) (Brown et al. 2020). Therefore, on the main outcome variable (half-marathon time), we used a novel statistical approach, called Two One-Sided Tests (TOST) equivalence testing procedure. Statisticians have specifically recommended the use of TOST equivalence testing in addition to the traditional null hypothesis significance testing (NHST) (Aisbett et al. 2020) to prevent common misinterpretation of p-values larger than the alpha level (Amrhein et al. 2019) as support for the absence of a true effect (Lakens 2017; Lakens et al. 2018). This analysis adds important information to the NHST as it tests the presence or the absence of meaningful effects.

Methods

Participants

Forty-eight male amateur long-distance runners were recruited. Two participants in the experimental treatment were excluded due to injury and premature exhaustion during the race. All participants signed a written, informed consent prior to participation. All procedures used were approved by the Ethics Committee from the University of Verona and were conducted in conformity with the Declaration of Helsinki.

Participants were recruited and tested over three editions (2015, 2016, 2017) of Run4Science. Run4Science is a competitive event (marathon and half-marathon) organised by the University of Verona (in collaboration with the Italian Athletics Federation and with the patronage of the city council) to give scientists the opportunity to study long-distance running in real-life conditions.

Subjects eligible for this study were involved in regular running (aerobic) training, free of any known disease, injury and medical treatment. In order to have a homogeneous fitness level, the recruited runners were first asked to complete a training-competition history questionnaire and a physical activity rating scale (PA-R) (Ross and Jackson 1991). Only those runners with a physical activity rating above 6 were included in the experiment.

Participants were not aware of the real aim and hypotheses of the experiment. They were told that the study aimed to investigate the effects of two different kinds of cognitive activities on physiological and psychological responses to a half-marathon race.

Study Protocol

A between-subject, posttest-only, randomized controlled design was used for this pragmatic trial. Participants were randomly asked either to perform a 50-min mentally-fatiguing task immediately before the half-marathon (experimental treatment) or to read some magazines for the same amount of time, always prior to the competition (control treatment). To control for the potential confounding effects of atmospheric conditions and other variables that may differ between the three races, participants at each data collection constituted a separate block and were randomly allocated to treatment as follows. To create two groups of equal size and similar maximal oxygen consumption ($\dot{V}O_{2max}$) at baseline, random allocation to treatment was performed in blocks of two participants ranked according to their $\dot{V}O_{2max}$ which was estimated using a validated multiple regression equation that takes into account subjects' PA-R (Ross and Jackson 1991), Body Mass Index (BMI), gender and age (Jackson et al. 1990). Participants' features (general and per group) are reported in Table 1. For statistical analysis, the three blocks of participants (one for each data collection) were pooled together.

The study took place at the Department of Neurosciences, Biomedicine and Movement Sciences, University of Verona. Both psychological and cognitive task interventions were carried out in a standardised lecture room. The half-marathon race took place in proximity to the School (See Fig.1A and 1B for the course).

One week prior to the half-marathon, runners were familiarized with the use of the 100-point rating of perceived exertion (RPE) scale (Borg 1998) and other questionnaires/scales (see *Psychological Questionnaires*). They were also informed to drink around 35 ml of water per kg of body weight, to sleep at least 7 hours, to refrain from alcohol consumption and to avoid strenuous exercise within the 24 hours preceding the experiment. Participants were also asked not to consume any caffeine and nicotine for at least 3 hours before the experiment.

On the race day, after a standardised breakfast (07:00-07:30 am), subjects were divided into two groups and asked to sit down either in the front (mental fatigue) or the back (control) of the lecture room. The experiment started at 08:00 am.

Participants were required to complete a mental and a physical fatigue scale (see *Psychological Questionnaires*). They were then asked to perform either the mental fatigue or the control task for 50 minutes (see *Treatment*). Immediately after the task subjects were required to complete the same fatigue scales completed at baseline. In order to assess subjective workload perceived during the treatment, and motivation and expectations related to the half-marathon race, participants completed a workload-related multidimensional scale, a motivation questionnaire and an expectation scale, respectively (see *Psychological Questionnaires*).

After the treatment and the completion of the psychological questionnaires participants performed the half-marathon race (the ranges of atmospheric conditions during the three data collections were:

temperature: 20.5-24.2 °C; humidity: 35%-53% RH; barometric pressure: 1013-1029 hPA). The course was a controlled 7-km circuit to be completed three times. The starting point was located inside the University outdoor track. Participants were equipped with a shoe race chip through which lap and overall performance times were taken. At the end of each lap athletes were required to run on the track and pass through the start, where RPE were collected. RPE was measured using the 100-point scale (Borg 1998). Two big posters of the same scale were placed in proximity of the starting point at 50-meter distance between each other. Subjects' heart rate (HR) and running speed were continuously collected throughout the entire race using GPS watches (Polar V800, Polar Electro Oy, Kempele, Finland). Participants were asked to do a 10-min warm-up immediately before the race. Participants were free to drink ad libitum during the race.

At the end of the race participants were asked to go back to the lecture room and to complete the same physical and mental fatigue scales related to the half-marathon race (see *Psychological Questionnaires*).

Treatment

In the mental fatigue group, treatment consisted in performing 50-min mentally-fatiguing tasks on a tablet screen (iPad Mini 2, Apple, California, USA). The mentally-fatiguing task was developed by Axon Sports (Phoenix, Arizona, USA), and consisted of five consecutive blocks of 10-mins, during which a simple response task and a search response task were run. In the simple response task participants were required to detect and press a visual stimulus (a green target) appearing randomly in the centre of the screen (stimulus frequency between 500 ms and 1500 ms). The total duration of the simple response task was 45 seconds per block. In the search response task participants were asked to detect and press a green target (go stimulus) and not to respond to a red target (no-go stimulus). Both stimuli appeared randomly in different positions on the screen (stimulus frequency between 750 ms and 1000 ms). A bleep sound was elicited in case of incorrect response. The total duration of the search response task was 9 minutes and 15 seconds per block. In the control group, treatment consisted in reading some magazines for 50 minutes, as it is considered a relaxing leisure activity (Kirsch and Guthrie 1984). Participants were continuously monitored by the researchers to guarantee compliance with both treatments.

Psychological Questionnaires

Mental and Physical Fatigue

Two Visual Analogue Scales (VAS) were used to assess mental and physical fatigue before and after treatment. The VAS used was the same one present in the multidimensional scale NASA Task Load Index (TLX) (Hart and Staveland 1988). It consists of a 100-mm horizontal line divided into 20 half-centimetres intervals. Subjects were asked to circle one of the 20 line intervals based on their current feelings of physical or mental fatigue. The total range of scores is between 0 and 20. The line ends are anchored by descriptors defining the extreme feelings of fatigue: “no fatigued at all” and “extremely fatigued”. Before statistical analysis, change scores (score after treatment minus score before treatment) were calculated for both physical and mental fatigue.

Subjective Workload

The multidimensional scale NASA TLX (Hart and Staveland 1988) was used to estimate subjective workload that participants experienced during the treatment. The NASA TLX includes six subscales which determine workload: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort and Frustration. Subjects were asked to circle one of the 20 line intervals on each of the six scales at the point which matched their experience. Each line has two endpoint descriptors “very low” and “very high” that describe the scale. The performance-related subscale goes from “good” on the left to “poor” on the right.

Motivation

Intrinsic motivation and success motivation scales (Matthews et al. 2001) were used to assess motivation related to the half-marathon race. Each scale includes 7 items to be scored on a 5-point Likert scale (where 0 = not at all, 1 = a little, 2 = somewhat, 3 = very much, 4 = extremely). The total range of scores for each scale is between 0 and 28.

Performance Expectations

The same VAS used in the NASA TLX was also adopted to measure participants’ expectations related to the half-marathon race. Subjects were asked to circle one of the 20 line intervals based on how well they expected to perform their race. The line ends are anchored by descriptors defining the extreme expectations: “much better than my personal best” and “much worse than my personal best”. A third descriptor “my personal best” was added to the centre of the VAS.

Statistical Analysis

The Shapiro-Wilk test, histograms, Q-Q plots and boxplots were used to check all data for normality. If data were not normally distributed, non-parametric tests were used.

Independent t-tests were used to analyse between-group differences in motivation and expectation scales, and the change score of mental fatigue. Mann-Whitney tests were used to test between-group differences in the change score of physical fatigue and the workload scales referred to the treatment.

An independent t-test was used to analyse the between-group difference in the half-marathon time. In addition, the TOST procedure (Lakens 2017; Lakens et al. 2018) was used to test the hypothesis that mental fatigue has no worthwhile effect on half-marathon time (equivalence). The smallest effect size of interest (SESOI) was decided a priori, with lower (Δ_L) and upper (Δ_U) bounds set to -0.26 and 0.26 (i.e. -2.947 and 2.947 min on a raw scale). Δ_L and Δ_U corresponded to the latest meta-analysis effect size (Hedge's *g*) of cognitive exertion on aerobic performance (Brown et al. 2020).

2 × 3 mixed-model ANOVAs (group x distance) were used to analyse differences in RPE, HR and running speed between the two groups during the half-marathon. When the assumption of sphericity was not met, the Greenhouse-Geisser correction was used. Significant interactions were followed up by testing simple main effects of the group at each distance with Bonferroni’s correction.

In the NHST analysis, statistical significance was accepted at $P < 0.05$ level. All data are presented as means ± SD, unless otherwise stated. RStudio (version 1.1.4; RStudio, Boston, MA) was used for the TOST equivalence testing analysis. The SPSS (version 23.0; SPSS, Chicago, IL) statistical package was used for all the other data analyses.

Results

Manipulation Checks

The difference in the mental fatigue change score was significant (mental fatigue 22.0 ± 21.6; control 7.1 ± 16.9; Cohen’s *d* = 0.773; *P* = 0.012), showing a greater increase in the mental fatigue group compared to the control group. No significant between-group difference was found for the physical fatigue change score (mental fatigue: *Mdn* = 0.00, Interquartile Range (*IQR*) = 3.75; control: *Mdn* = 0.00, *IQR* = 10.00; *U* = 245.00, *z* = - 0.44, *r* = - 0.07; *P* = 0.662). The multidimensional scale NASA TLX completed immediately after the treatment showed a trend toward significant higher values of mental demand in the mental fatigue group (*Mdn* = 42.50, *IQR* = 61) compared to the control group (*Mdn* = 25.00, *IQR* = 30) (*U* = 176.50, *z* = - 1.93, *r* = - 0.30; *P* = 0.053). The same multidimensional scale also revealed that the mental fatigue group (*Mdn* = 47.50, *IQR* = 53) provided significantly higher ratings of effort (*Mdn* = 25.00, *IQR* = 45) (*U* = 164.00, *z* = - 2.21, *r* = - 0.33; *P* = 0.027) and temporal demand (mental fatigue: *Mdn* = 50.00, *IQR* = 53; control: *Mdn* = 10.00, *IQR* = 14; *U* = 106.00, *z* = - 3.49, *r* = - 0.51; *P* < 0.001) than the control group. Ratings of physical demand, performance and frustration were not significantly different between the two groups.

Intrinsic motivation (mental fatigue 23.0 ± 2.5; control 23.1 ± 3.0; Cohen’s *d* = 0.030 ; *P* = 0.919) and success motivation (mental fatigue 16.4 ± 3.1; control 16.1 ± 3.3; Cohen’s *d* = 0.074; *P* = 0.802) did not differ significantly between the two groups. Expectations related to the half-marathon performance also did not differ significantly between groups (mental fatigue 43.2 ± 22.4; control 45.2 ± 14.1; Cohen’s *d* = 0.110; *P* = 0.713).

Effect of Mental Fatigue on Half-Marathon Performance

The NHST analysis (independent t-test) showed no significant difference between the two groups (mental fatigue 106.2 ± 12.4 min; control 102.4 ± 10.2 min; 95% CI [-3.0, 10.5 min]; Cohen’s *d* = 0.333; *P* = 0.265)

(Fig.2). The TOST procedure revealed no significant equivalence ($t(40.88) = 0.239$, $P = 0.594$). Inspection of the 90% confidence limit of the difference between the two groups (90% CI [-1.9, 9.4 min]) in relation to the upper and lower equivalence bounds of the SESOI (Fig.3) shows that whilst the presence of a worthwhile beneficial effect of mental fatigue can be excluded, the presence of a worthwhile harmful effect cannot be excluded. Indeed, whereas the test against Δ_L shows that differences equal or smaller than -2.947 min can be rejected, the test against Δ_U indicates that effects at least as extreme as 2.947 min cannot be rejected.

Effects of Mental Fatigue on running speed, HR, and RPE

No significant group x distance interactions were found on running speed ($P = 0.910$), HR ($P = 0.829$), and RPE ($P = 0.582$). Running speed showed a significant decrease over distance in both groups ($P < 0.001$). However, no significant difference was found between groups (Cohen's $d = 0.274$, $P = 0.358$) (Fig.4A). HR showed a significant increase over distance in both groups ($P < 0.001$). However, no significant difference was found between groups (Cohen's $d = 0.391$, $P = 0.192$) (Fig.4B). RPE also increased significantly over distance in both groups ($P < 0.001$). However, no significant difference was found between groups (Cohen's $d = 0.162$, $P = 0.586$) (Fig.4C).

Discussion

Effect of Mental Fatigue on Half-Marathon Performance

Participants reported that the mentally-fatiguing task was mentally demanding and effortful, and it increased the feelings of mental fatigue significantly more than the control treatment (reading magazines). Therefore, the experimental treatment used in this study was successful in inducing a state of mental fatigue.

The traditional NHST analysis showed that mental fatigue did not have a significant effect on half-marathon performance. At first glance, this result is contrary to the results of most previous laboratory/indoor-based studies on the effects of mental fatigue on shorter-term endurance performance (Marcora et al. 2009; Pageaux et al. 2013, 2014; MacMahon et al. 2014). However, finding a *P* value larger than 0.05 or a 95% confidence interval including zero does not necessarily mean that there is 'no difference', 'no effect' or 'no association' (Amrhein et al. 2019). Participants in the mental fatigue group completed the race, on average, four minutes slower than the participants in the control group with an effect size of 0.333 (Cohen's *d*). This effect size is similar to the effect sizes found in previous within-subject, lab-based experiments in which the effect of mental fatigue on endurance performance was statistically significant (Marcora et al. 2009; Pageaux et al. 2014). Furthermore, the effect size in our pragmatic trial is larger than the significant pooled effect size (Hedge's $g = 0.26$) found for the effect of prior cognitive exertion on aerobic performance in a recent meta-analysis of lab-based studies (Brown et al. 2020). Therefore, the most likely explanation for the lack of statistical significance is a lack of statistical power due to the obligatory between-group, posttest-only design of our pragmatic trial rather than the absence of a negative effect. Indeed, with such experimental design, a sample size of 472 runners (236 per group) would be necessary for a Cohen's $d = 0.333$, alpha = 5% and beta = 20%. It is clear that conducting experiments of such sample size during real-life endurance competitions is extremely difficult. Due to the limited funding available and the logistical barriers to recruitment and testing, the maximum number of participants we were able to recruit over three consecutive years was 48. Therefore researchers should not rely on the NHST only, but should also use alternative and more suitable statistical approaches (Harrison et al. 2020).

In order to prevent the common misinterpretation of *P*-values larger than the alpha level as support for the absence of a true effect (Lakens 2017; Lakens et al. 2018), we also implemented the TOST equivalence testing procedure (Lakens 2017; Lakens et al. 2018). This novel statistical approach has been proposed as a more valid alternative to the magnitude based inference approach, previously used in sport performance research and recently rejected by statisticians and scientific journals (Aisbett et al. 2020; Harrison et al. 2020). The TOST equivalence testing procedure rejected the hypothesis that mental fatigue has a beneficial effect on half-marathon performance in amateur runners but failed to reject the hypothesis that it has no worthwhile harmful effect (Fig.3). In other words, the results of the present study demonstrate that mental fatigue can either have no worthwhile effect or a worthwhile detrimental effect on half-marathon performance in amateur runners.

Potential Mechanisms

Notwithstanding the limitations with regards to NHST analysis and lack of adequate power in our pragmatic trial, it is worth briefly discussing the effects of mental fatigue on other variables as they may provide some hints to the mechanisms underlying the potential negative effect of mental fatigue on long-term endurance performance.

Very small effect sizes and no statistically significant differences were found for success motivation, intrinsic motivation, and performance expectations. Therefore, it is unlikely that the potential negative effect of mental fatigue on half-marathon performance in amateur runners was mediated by a large reduction in motivation or a nocebo effect caused by the experimental treatment (Boot et al. 2013).

In agreement with previous studies (Nikolaidis et al. 2019; Cuk et al. 2019, 2020), the present experiment showed that running speed significantly decreased throughout the half-marathon in both groups (i.e. positive pacing pattern, which consists in a fast start followed by a progressive reduction in running speed). Even though no statistically significant differences were found between the two groups, running speed in the mental fatigue group was on average 3% slower than in the control group. Heart rate values were also 3% lower throughout the entire race in the mental fatigue group compared to the control group. Moreover, RPE during the race was similar (at 7 km) or higher (at 14 and 21 km) in the mental fatigue group compared to the control group. The directions of these between-group differences are consistent with the significant differences observed in more powerful within-subject studies showing that mental fatigue (Van Cutsem et al. 2017) and the fatigue that accumulates during multi-day races (Sanders et al. 2018) are associated with an increase in RPE for a given speed/power or HR. According to the psychobiological model of self-paced endurance performance (Marcora 2010; Pageaux 2014), such increase in perception of effort would lead to the conscious decision to reduce the running speed during the half-marathon race in order to avoid premature exhaustion with the consequent reduction in HR and the increase in half-marathon time. The directions of the changes in running speed, HR, RPE and half-marathon time observed in the present study are consistent with such theoretical prediction and the results of previous studies on the effects of mental fatigue on self-paced endurance performance tests in the laboratory or on an indoor track (Brownsberger et al. 2013; Pageaux et al. 2014; MacMahon et al. 2014).

Practical Applications and Directions for Future Research

In conclusion, because of low statistical power, the data collected do not provide reliable evidence that mental fatigue reduces long-term endurance performance. However, the effect size of the present study is in line with previous studies on shorter-term endurance performance (Van Cutsem et al. 2017). Furthermore, the TOST procedure suggests that mental fatigue can either have no worthwhile effect or a worthwhile detrimental effect on half-marathon performance in amateur runners. Given that avoiding mentally-fatiguing tasks before a race is feasible and without negative side effects, it seems prudent to recommend that endurance athletes avoid or reduce engagement in tasks that may induce mental fatigue (e.g. dealing with transport and logistics, or inhibiting emotions) before any race, including those lasting more than 45 minutes. Because sleep deprivation exacerbates mental fatigue (Wesensten et al. 2004), endurance athletes should also implement strategies to improve their sleep before an important race (Halson and Juliff 2017).

Additional studies with much larger sample size or two races (baseline and follow-up) will be required to draw a firmer conclusion on the hypothesis that mental fatigue has a negative effect on endurance events longer than 45 minutes, and to provide more precise estimates of the effects of mental fatigue on endurance performance during outdoor mass-start competitions. Given some evidence that elite endurance athletes may be more resistant to mental fatigue than amateurs (Martin et al. 2016), future studies should include participants of higher competitive level. Further research is also required to confirm our hypothesis that the main mediator of the negative effect of mental fatigue on long-term endurance performance is primarily the increase in perception of effort associated with mental fatigue.

Abbreviations

ANOVA	Analysis of variance
BMI	Body Mass Index
CI	Confidence Interval

H_o Null hypothesis

HR Heart rate

IQR Interquartile range

NHST Null hypothesis significance testing

PA-R Physical activity rating

RPE Rating of perceived exertion

SESOI Smallest effect size of interest

$\dot{V}O_{2max}$ Maximal oxygen consumption

TLX Task Load Index

TOST Two One-Sided Tests

VAS Visual Analogue Scales

Δ_L Lower equivalence bound

Δ_U Upper equivalence bound

Declarations

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Conflicts of interest/Competing interest

One of the co-authors (BVO) was previously employed by GSK which also provided financial support to Dr Chiara Gattoni during her PhD, including the current study.

Availability of data and material

The data sets generated during and/or analysed during the current study are available from Dr Chiara Gattoni on reasonable request.

Code availability

Not applicable

Author contributions

Conception or design of the work: CG and SMM

Acquisition, analysis or interpretation of data for the work: CG and SMM

Drafting the work or revising it critically for important intellectual content: CG, BVO, FS and SMM

All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed.

Compliance with ethical standards

Ethical approval

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee (Ethics Committee of the University of Rome Sapienza) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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Figures

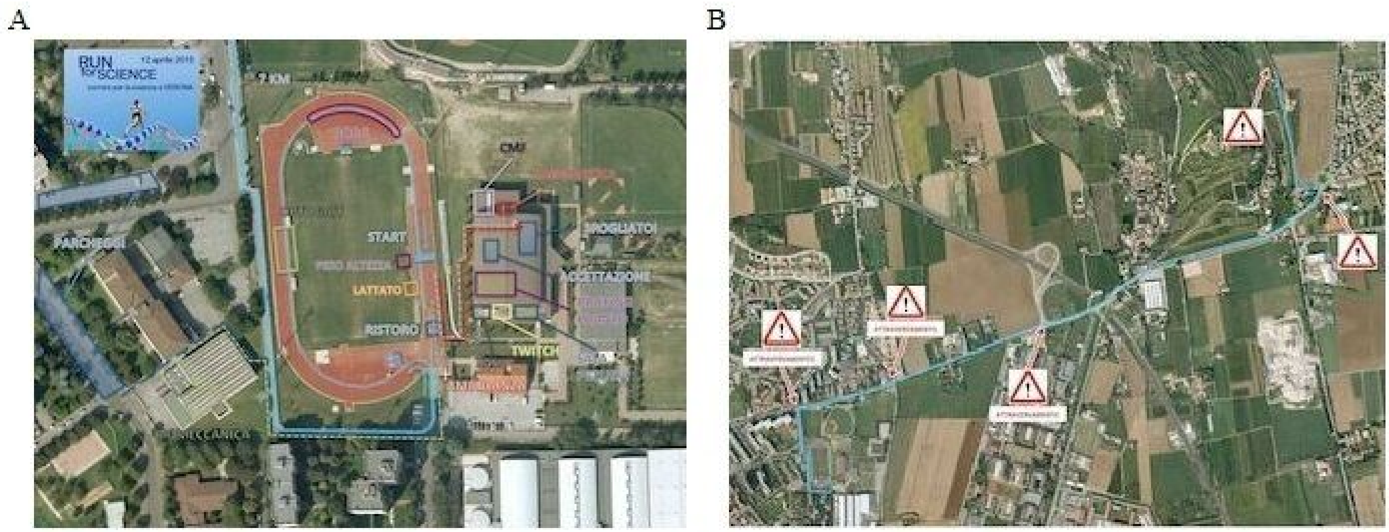

Figure 1

The outdoor track where the race started-finished and lap time/rating of perceived exertion were recorded (Panel A), and the 7-km circuit course of the race (Panel B) that was repeated three times.

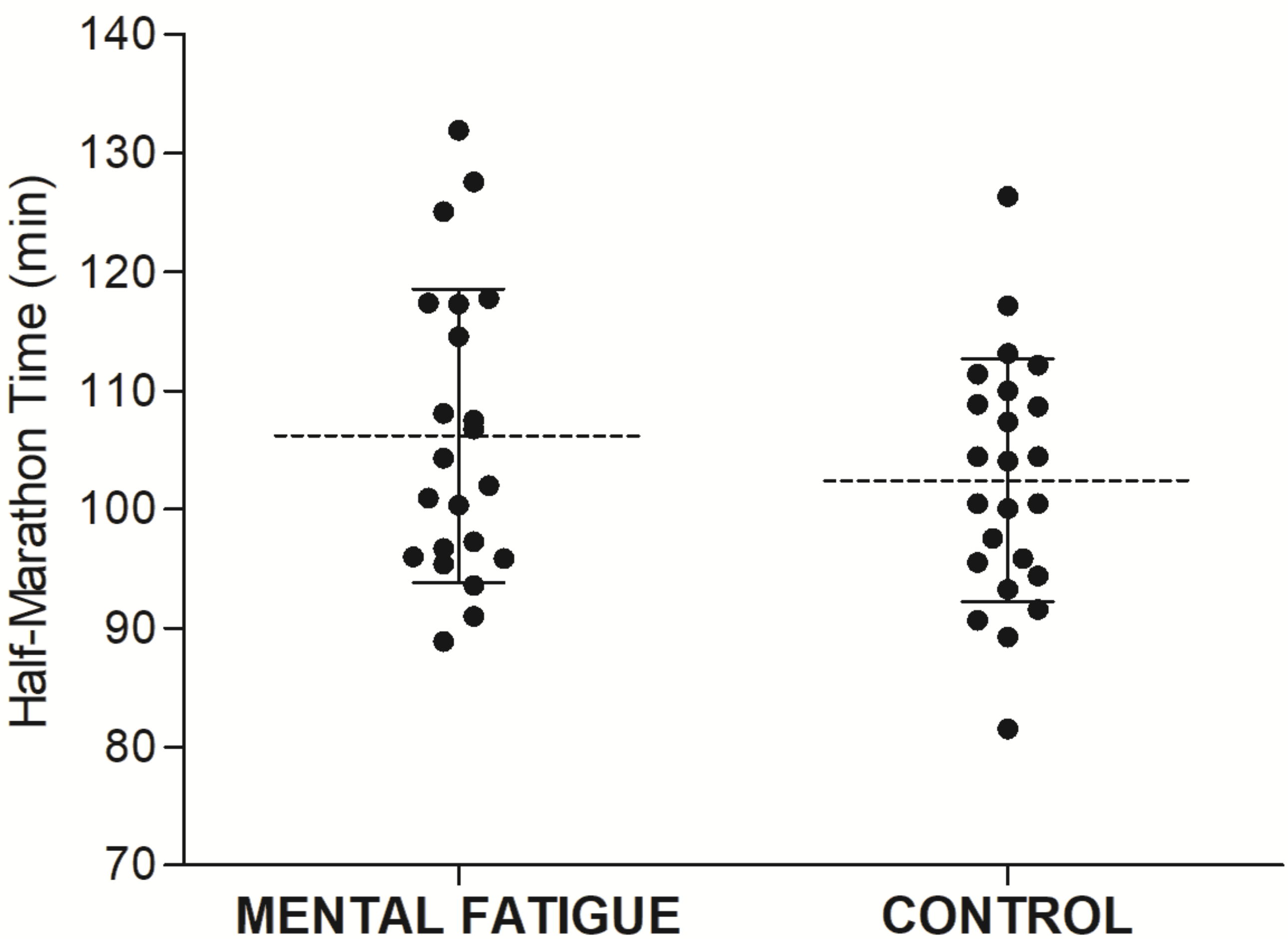

Figure 2

Half-marathon time in the mental fatigue group and the control group. Dots represent individual data whilst horizontal lines represent means (open lines) and standard deviations (solid lines).

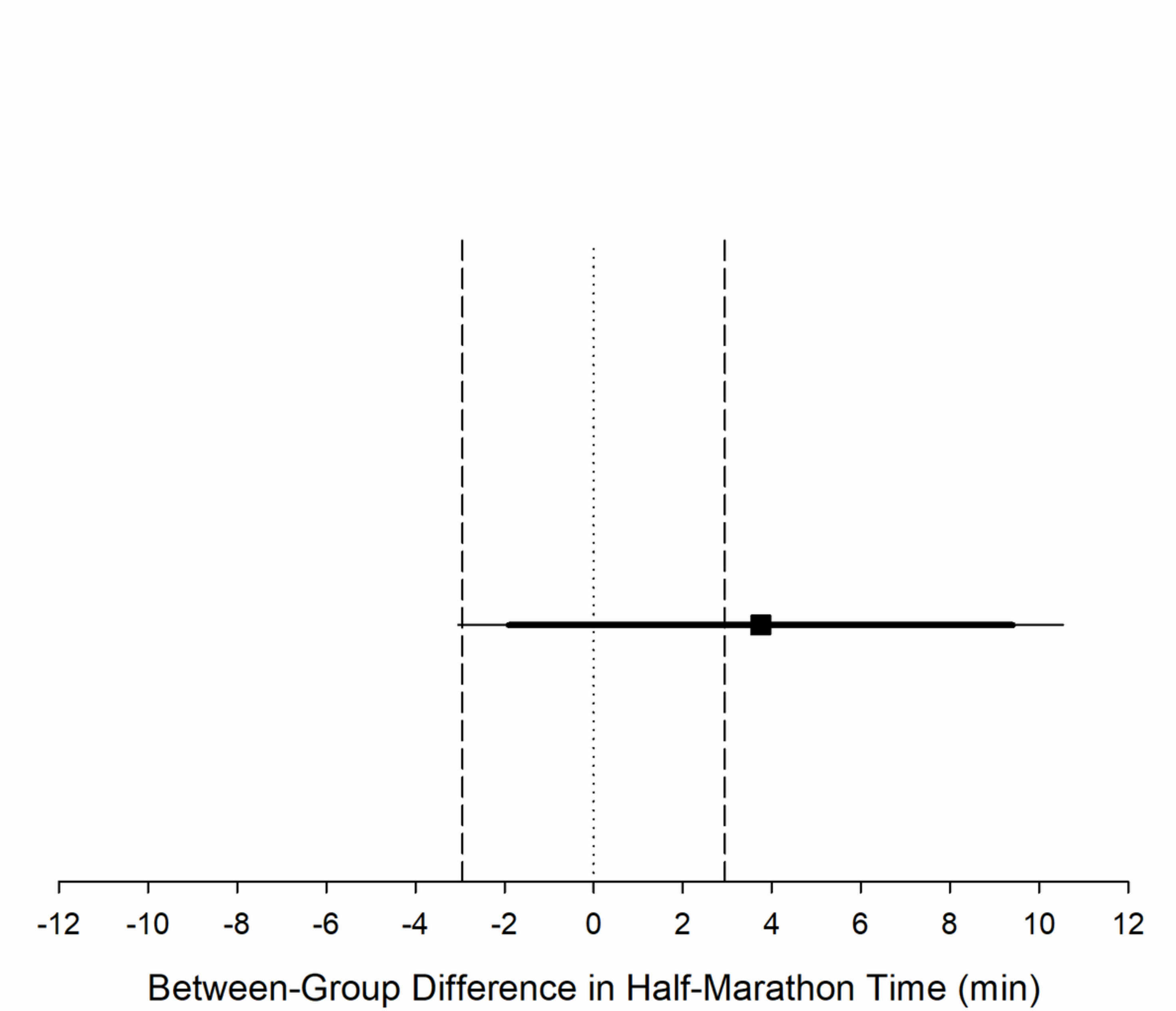

Figure 3

Difference in half-marathon time between the mental fatigue group and the control group (black square). The thick horizontal line indicates the 90% confidence interval for such difference whereas the thin horizontal line indicates the 95% confidence interval. The dotted vertical line indicates the null hypothesis whilst the dashed vertical lines indicate the equivalence bounds in raw score.

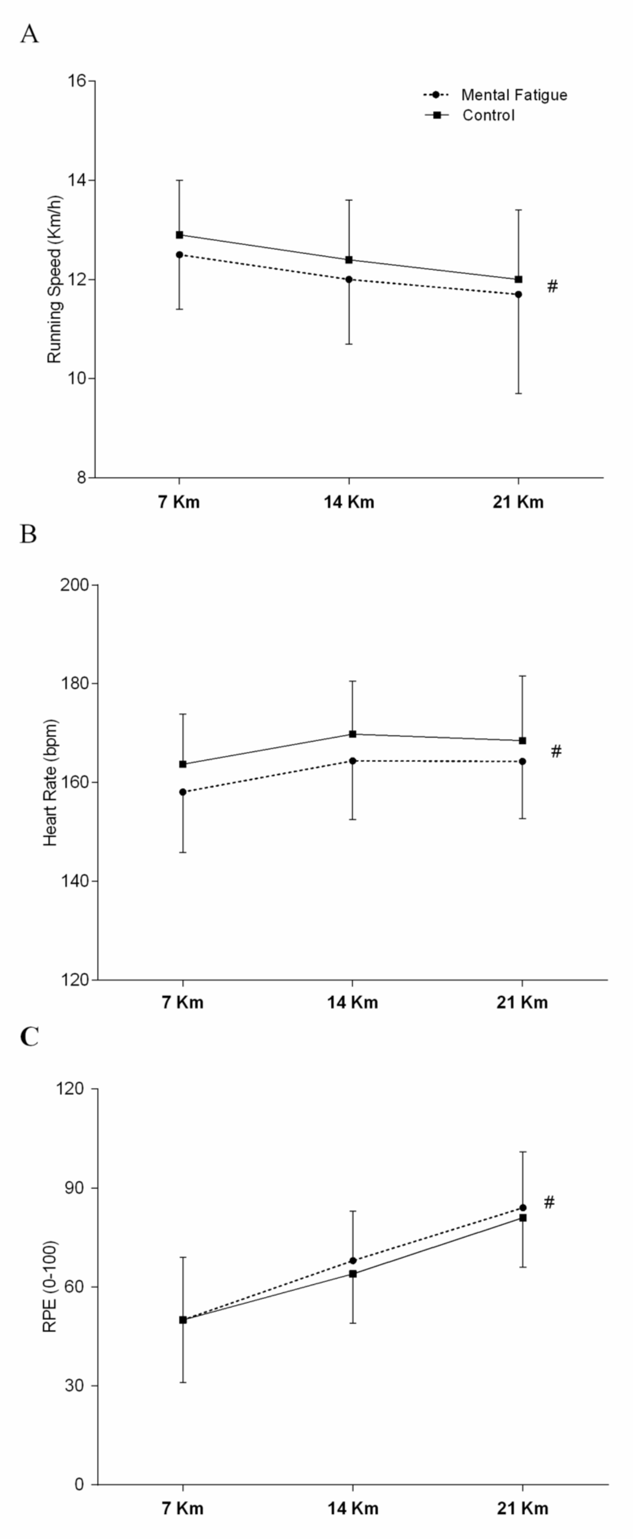

Figure 4

Running speed (A), heart rate (B) and rating of perceived exertion (RPE) (C) during the half-marathon race in the mental fatigue group and the control group. Data are presented as mean ± SD. # Significant main effect of distance ($p < 0.05$).