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How am I doing? Performance feedback mitigates the effects of mental fatigue on endurance exercise performance

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A B S T R A C T

Mental fatigue induced by an earlier cognitive task can impair performance on a subsequent physical task. The current study investigated whether such performance impairment could be mitigated by performance feedback. In an experimental sequential-task design, 63 sport science students completed a series of three tasks: 5-min physical (pre-test), 20-min cognitive, 5-min physical (post-test). Participants were randomly allocated to one of three groups: feedback ($n = 23$), no feedback ($n = 20$), control ($n = 20$). The physical tasks, which assessed force production during a self-paced rhythmic handgrip task as a measure of physical endurance performance, were performed with (feedback group) or without (no feedback group, control group) visual performance feedback. The cognitive tasks involved either completing a 2-back memory task to induce mental fatigue (feedback and no feedback groups) or watching a didactic film (control group). Self-report measures (fatigue, exertion, vigor, motivation) were collected throughout. The 2-back cognitive task increased mental fatigue, mental exertion and general fatigue in the feedback and no feedback groups compared to the control group. Relative to the pre-test physical task, post-test endurance performance declined in the no feedback group (−14.4%) but did not change in the control (−2.6%) and feedback (−2.4%) groups. This mitigation of performance effect was not accompanied by parallel changes in fatigue, exertion, vigor, or motivation. In conclusion, visual performance feedback mitigates the negative effects of mental fatigue on physical endurance performance.

1. Introduction

Mental fatigue, a psychobiological state caused by prolonged demanding cognitive activity (Martin et al., 2018), can negatively affect physical performance (for review see Van Cutsem et al., 2017). For example, experiments using the sequential-task paradigm have shown that cognitive tasks, that elicit mental fatigue, can impair subsequent performance on endurance exercise tasks, such as cycling (Marcora et al., 2009) and handgrip (Bray et al., 2012). The theoretical basis, underlying mechanism, and interventions for this phenomenon have yet to be established although it is often proposed to be due to an elevated sense of effort (Martin et al., 2018; Van Cutsem et al., 2017).

The *psychobiological model* (Marcora, 2007, 2008) offers an account of how the brain regulates endurance exercise. At its core, the model proposes that the decision to terminate exercise lies within the conscious brain. Based on *motivational intensity theory* (Gendolla & Richter, 2010), the model argues that task performance is determined by perceived exertion and motivation (Boksem et al., 2006; Marcora & Staiano, 2010; McCormick et al., 2015), whereas task termination occurs when the effort required to continue performing a task equals the maximum effort someone is willing to expend (Brehm & Self, 1989). In other words, participants are motivated to perform a task up to a point – namely, when costs exceed benefits – and thereafter motivation to persist declines (Boksem & Tops, 2008). Accordingly, mental fatigue, when viewed as a cost to the performer, can undermine their motivation and curtail endurance.

Several methods have been shown to improve physical performance. One such method is the provision of performance feedback. Although some studies have reported no difference in performance between feedback and no feedback groups (e.g., Kanemura et al., 1999; Warren et al., 2010), most studies find that feedback during exercise benefits performance. For instance, verbal performance feedback increased resistance exercise work rate (Argus et al., 2011). Similarly, visual performance feedback increased cycling speed and distance covered (MacRae, 2003), increased isokinetic exercise performance (Kim & Kramer, 1997; Stastny et al., 2018), and increased peak torque during maximum voluntary isokinetic contractions (Kanemura et al., 1999). As well as improving performance, the provision of feedback can also influence psychological processes, including improved motivation, during strength and conditioning exercises (Weakley, et al., 2020; Wilson et al., 2017; 2018). Moreover, the surreptitious provision of augmented feedback can also benefit exercise performance. False feedback – whereby participants were made to believe they were racing to beat performance on an earlier trial – improved 4 km time trial performance by 2% more

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than control (Stone et al., 2012; 2017). It has been suggested that this beneficial effect on performance may be explained by increased motivation and/or improved strategy (e.g., Williams et al., 2014; 2015). External pacing – whereby participants were provided with a virtual avatar portraying their previous best performance in a simulated time trial – also improved time trial performance (Williams et al., 2014). This effect was explained by changes in attention, whereby they focused on the external avatar and away from internal sensations.

Although it is now well established that mental fatigue can impair performance during exercise endurance events (Van Cutsem et al., 2017), there are currently few interventions available to help athletes deal with this problem. In terms of chronic interventions, brain endurance training, whereby athletes train while mentally fatigued, offers a potential solution (e.g., Dallaway et al., 2021), however, this requires a long-term training program. In terms of acute interventions, the use of caffeine-maltodextrin mouth rinse may counteract the effects of mental fatigue during exercise (Van Cutsem et al., 2018), however, health-related side-effects (Ammon, 1991) limit enthusiasm for this oral supplement. Accordingly, additional evidence-based interventions are needed.

No study, to our knowledge, has investigated performance feedback as an intervention to prevent mental fatigue impairing physical performance. We adopted a sequential-task design with three tasks: exercise task, cognitive task, and exercise task. Our study purposes were threefold. Our first study purpose was to examine the effect of performance feedback on muscular endurance performance whilst in a state of mental fatigue. We hypothesized that visual performance feedback would prevent mental fatigue from impairing endurance performance on a 5-min rhythmic muscular endurance handgrip task. Our second study purpose was to examine the effect of performance feedback on psychological processes. We hypothesized that performance feedback would decrease fatigue and increase effort and motivation during the exercise task. Finally, our third study purpose was to investigate whether the effects of performance feedback were moderated by sex. Previous fatigue-performance studies have yielded mixed findings, with sex differences reported by some (e.g., Yoon et al., 2009) but not others (e.g., Bray et. al., 2012, 2008; Lopes et al., 2020). Accordingly, we explored the role of sex in our study but made no explicit predictions regarding the moderating effects of sex on the effects of feedback on the fatigue-performance relationship.

2. Method

2.1. Participants

Sixty-three undergraduate sport and exercise science students (36 men, 27 women), with a mean age of 21.8 (SD ± 1.5) years, participated. Exclusion criteria included current illness, history of arm injury, and current participation in upper body strength training. Participants were asked to refrain from vigorous exercise and alcohol (24 h), consuming caffeine (>3 h), smoking (>2 h), and eating (>1 h) prior to testing. They were also asked to sleep well (>7 h) the night before. The study was approved by the local research ethics committee and all participants provided written informed consent.

2.2. Design and procedure

The study employed an experimental design with one between-participant two factors (group: feedback, no feedback, control; sex: male, female,) and one within-participant factor (test: pre-, post-). Participants completed a 60-min laboratory testing session. Following instrumentation and instruction, the participant's maximum voluntary contraction (MVC) was recorded. Using a sequential-task design, participants completed a series of three tasks: 5-min physical (pre-test), 20-min cognitive (2-back or film), 5-min physical (post-test). Participants were randomly allocated to one of three groups: feedback ($n = 23$), no feedback ($n = 20$), control ($n = 20$). The physical tasks assessed force production during a self-paced rhythmic handgrip task as a measure of physical endurance performance, and they were performed with (feedback group) or without (no feedback and control groups) visual performance feedback. The cognitive task involved either completing a 2-back memory task to induce mental fatigue (feedback and no feedback groups) or watching a didactic film to induce relaxation (control group). Participants provided ratings before and after each task. They received instruction and familiarisation for each task. A £20 retail voucher was offered for the best overall task performance in each group. The force signal from the handgrip dynamometer was acquired through a Power 1401 (Cambridge Electric Design Limited UK) multi-channel analogue-to-digital convertor (16-bit resolution at a sampling rate of 2.5 kHz) and the output continuously recorded on a computer using Spike 2 software (version 6.06). The protocol is summarized in Figure S1 (**Supplementary Materials**).

2.3. Maximum voluntary contraction (MVC)

Participants were instructed to squeeze a handgrip as hard as possible for several seconds in order to obtain their maximum voluntary contraction (Cooke et al., 2011). They were not aware that their peak force informed the subsequent physical task. A bespoke handgrip dynamometer (Radwin et al., 1991) was held in their dominant hand (i.e., the one they used to write with), placed on their knee, with their arm flexed at approximately 100°. Participants performed a maximal contraction of the handgrip, and the peak force was recorded. This was repeated three times, with each contraction separated by a 1-min rest to allow recovery, with the largest peak force achieved recorded as their maximum voluntary contraction. If the second highest peak force was not within 5% of the highest another attempt was required.

2.4. Physical task

The physical task required participants to hold the handgrip dynamometer in the same position as during the maximum voluntary contraction and to squeeze it with their dominant hand once a second (1 Hz), indicated by an audio metronome, for 5 min (Figure S2, **Supplementary Materials**). A standardised script was read to participants before the task, at 150 s, and at 270 s, instructing them to "*generate as much force as possible in the timeframe for a chance of winning a £20 voucher*". The task time was indicated to participants at 60, 120, 180, 240 and 295 s alongside reports of ratings of physical exertion. Performance was determined by the average peak force as a percentage of MVC per second (force %MVC/s) over the 5-min task. A 1-min familiarisation task with visual performance feedback was completed after the maximum voluntary contraction task.

The feedback group was provided with (a) continuous visual performance feedback during the physical task at both pre-test and post-test (Figure S3, Supplementary Materials), and (b) summary performance feedback of their pre-test task performance immediately prior to beginning the post-test task. The no feedback and control groups did not receive any feedback.

2.5. Cognitive task

2-back task. The feedback and no feedback groups completed a 2-back task. The 2-back task (Braver et al., 1997) involves attention and working memory but does not involve response inhibition (Owen et al., 2005). The 2-back task has been shown to increase mental fatigue (e.g., Dallaway et al., 2022; Tanaka et al., 2009) and impair performance on a subsequent rhythmic handgrip task (Dallaway et al., 2022). Participants were presented with a continuous series of random consonants in the centre of a computer monitor for 500 ms, followed by a blank display for 3 s requiring participants to respond indicating if the current letter displayed was the same (target) or different (non-target) as the letter displayed two previously using a computer keyboard with their non-dominant hand. Letters were displayed with a 1:2 target to non-target ratio. Performance was determined by the percentage correct responses. Participants were verbally briefed on the task and presented with written instructions prior to the familiarisation period and performance task. of random consonants: they were required to indicate if the current letter displayed was the same as the one presented two letters earlier. The task was implemented using E-Studio (version 2.0.1.97, Psychology Software Tools, Inc., USA).

Control task. The control group watched a documentary film about trains: Venice Simplon Orient Express, World Class Trains (Garofalo, 2004). The film, which has been used as a control task in previous sequential-task studies (Marcora et al., 2009; Martin et al., 2015), is emotionally neutral and elicits stable physiological responses (Silvestrini & Gendolla, 2007). They watched the first minute as a familiarisation task.

2.6. Measures

Fatigue and exertion. The cognitive tasks were rated immediately following completion for mental exertion and mental fatigue on 10-point category ratio (CR-10) scales. The mental exertion scale was anchored with the extreme descriptors “nothing at all” and “maximal mental exertion”. The mental fatigue scale was anchored with the extreme descriptors “nothing at all” and “totally exhausted”. Participants were reminded that these scales related to mental tiredness and exertion and not physical sensations. Following the cognitive and physical task, items (exhausted, sleepy, tired, worn-out) from the fatigue subscale of the profile of mood states (POMS) were rated on a 5-point scale with anchors of 1 “not at all” and 5 “extremely” (Terry et al., 2003). Ratings of perceived exertion (RPE) were given verbally on a 10-point CR-10 scale (Borg, 1982), anchored with the descriptors “nothing at all” and “maximal”. The standard instructions for the scale (Borg, 1998) were read to participants prior to each physical task.

Motivation. Success motivation was measured using subscale from the extrinsic motivation scale (Matthews et al., 2001): participants rated four items (e.g. “I am eager to do well”, “I want to perform better than most people do”) on a 5-point scale, with anchors of 1 = “not at all” and 5 = “extremely”. Task interest and enjoyment was measured using the interest/enjoyment subscale of the intrinsic motivation inventory (McAuley et al., 1989). Participants were presented with seven items (e.g., “I enjoyed doing this activity very much”, “I would describe this activity as very interesting”), and responded on a 7-point scale, with anchors of 1 “not true at all” and 7 “very true”.

2.7. Statistical analysis

A series of 3 group (feedback, no feedback, control) by 2 sex (male, female) by 2 test (pre-test, post-test) mixed factorial ANOVAs were performed on the performance and self-report measures. A 3 group (feedback, no feedback, control) by 2 sex (male, female) by 2 test (pre-test, post-test) by 5 min (1, 2, 3, 4, 5) mixed factorial ANOVA on force per second served to examine pacing strategy during the handgrip task. Partial eta-squared (η_p^2) was reported as a same measure of effect size with values of 0.02, 0.13 and 0.26 indicating small, medium, and large effect sizes, respectively (Cohen, 1992). Significant ANOVA effects were followed by least significant difference post-hoc tests. The multivariate approach was reported for all within-participant effects where appropriate (Vasey & Thayer, 1987). Significance was set at $p < .05$. Analyses were conducted using the Statistical Package for the Social Sciences (SPSS) software (SPSS: An IBM Company, Chicago, IL, United States).

3. Results

3.1. Cognitive task

A series of 3 group by 2 sex ANOVAs confirmed that the 2-back task completed by the feedback and no feedback groups elicited more mental fatigue, mental exertion, and general fatigue than the didactic film watched by the control group (Table 1). A 2 group (feedback, no feedback) by 2 sex ANOVA confirmed that performance on the 2-back task was similarly high for both the feedback ($M = 90.21$ percent correct) and no feedback ($M = 88.20$ percent correct) groups, $F(1, 39) = 0.60$, $p = .38$, $\eta^2 = 0.02$. These manipulation checks confirm that the 2-back task was successful in engaging participants and eliciting a state of increased mental fatigue. No sex differences were identified.

3.2. Physical task

Physical task performance (Figure 1) was analysed using a 3 group (feedback, no feedback, control) by 2 sex (male, female) by 2 test (pre-test, post-test) ANOVA on the amount of force produced, expressed as a percentage of MVC per second, during the 5-min physical task. This

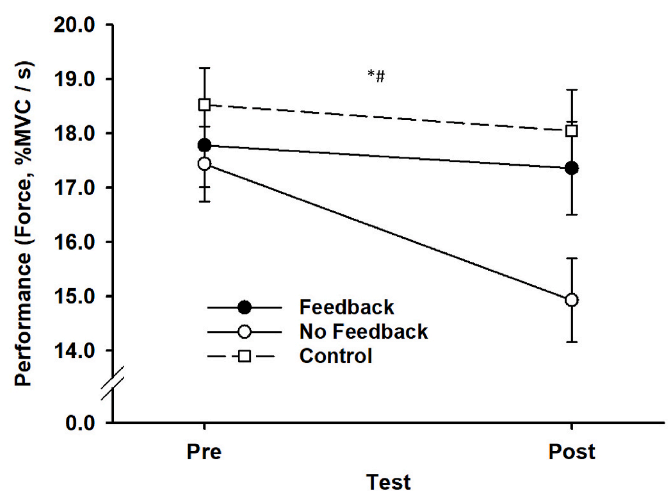

Figure 1. Mean (SE) endurance performance during the physical task as a function of group (feedback, no feedback, control) and test (pre-test, post-test). * test main effect ($p < .001$). # group by test interaction effect ($p < .002$).

Table 1
Mean (95% *CI*) self-report measures following the cognitive task as a function of group (feedback, no feedback, control).

	Group				
Measure	Feedback	No Feedback	Control	F(2, 57)	η^2
Mental Fatigue	5.66 ^{c} (4.47, 6.85)	5.84 ^{c} (4.78, 6.90)	2.44 (1.39, 4.49)	12.73 ***	.31
Mental Exertion	7.34 ^{c} (6.32, 8.35)	6.19 ^{c} (5.29, 7.10)	1.52 (0.62, 2.41)	44.14 ***	.61
General Fatigue	3.16 ^{c} (2.68, 3.63)	3.10 ^{c} (2.68, 3.52)	2.10 (1.68, 2.52)	7.67 ***	.21
Vigor	2.50 (2.05, 2.96)	2.49 (2.08, 2.89)	2.56 (2.16, 2.96)	0.04	.00
Success Motivation	2.41 (1.91, 2.92)	2.63 (2.18, 3.07)	2.21 (1.77, 2.66)	0.86	.03
Enjoyment/Interest	3.23 (2.52, 3.95)	3.22 (2.59, 3.86)	2.83 (2.20, 3.46)	0.51	.02

Superscript ^{c} indicates significant ($p < .05$) difference from control group. ***$p < .001$

Table 2
Mean (95% *CI*) self-report measures following and during (perceived exertion only) the physical task as a function of group (feedback, no feedback, control) and test (pre-test, post-test).

	Feedback Group		No Feedback Group		Control Group	
Measure	Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
Mental Fatigue	1.95 (1.18, 2.72)	3.42 (2.47, 4.37)	1.93 (1.25, 2.62)	3.18 (2.34, 4.03)	1.64 (0.95, 2.32)	2.20 (1.36, 3.04)
Mental Exertion	2.13 (1.26, 3.00)	2.91 (1.94, 3.88)	2.12 (1.35, 2.89)	2.99 (2.12, 3.85)	1.45 (0.68, 2.22)	1.80 (0.94, 2.66)
General Fatigue	2.24 (1.89, 2.58)	2.81 (2.41, 3.21)	2.30 (1.99, 2.60)	2.95 (2.59, 3.30)	2.16 (1.86, 2.47)	2.28 (1.92, 2.63)
Vigor	3.01 (2.57, 3.47)	2.72 (2.28, 3.16)	2.95 (2.55, 3.35)	2.61 (2.21, 3.00)	3.28 (2.88, 3.67)	3.18 (2.79, 3.57)
Success Motivation	2.43 (1.95, 2.91)	2.25 (1.72, 2.78)	2.47 (2.05, 2.90)	2.15 (1.68, 2.63)	2.51 (2.09, 2.94)	2.38 (1.90, 2.85)
Enjoyment/Interest	3.66 (3.02, 4.30)	3.61 (2.92, 4.29)	3.29 (2.72, 3.86)	3.11 (2.50, 3.72)	3.58 (3.02, 4.14)	3.64 (3.04, 4.25)
Perceived Exertion	6.29 (5.49, 7.09)	6.48 (5.74, 7.22)	5.45 (4.73, 6.16)	5.69 (5.03, 6.35)	4.19 (3.48, 4.90)	4.45 (3.80.5.11)

revealed a main effect for test, $F(1, 57) = 19.08$, $p < .001$, $\eta^2 = 0.25$, whereby force fell from pre-test ($M = 17.92$ %MVC/s) to post-test ($M = 16.78$ %MVC/s), and a group by test interaction effect, $F(2, 57) = 7.22$, $p < .002$, $\eta^2 = 0.20$. Follow-up analyses confirmed that performance of the feedback and control groups was unchanged whereas the performance of the no feedback group fell from pre-test to post-test. Moreover, the difference in performance from pre-test to post-test was less negative in the feedback ($M\Delta = -0.42$ %MVC/s, $p = .04$) and control ($M\Delta = -0.48$ %MVC/s $p = .01$) groups compared to the no feedback group ($M\Delta = -2.51$ %MVC/s). Finally, a 3 group by 2 sex ANOVA confirmed that maximum grip strength did not differ among the groups, $F(2, 57) = 1.38$, $p = .26$, $\eta^2 = 0.05$; $M_{MVC} = 400 \pm 110$ N.

Pacing strategy during the physical tasks was analysed using a 3 group (feedback, no feedback, control) by 2 sex (male, female) by 2 test (pre-test, post-test) by 5 time (1, 2, 3, 4, 5) ANOVA on the amount of force produced, expressed as a percentage of MVC per second, revealed a main effect for test, $F(1, 57) = 20.32$, $p < .001$, $\eta^2 = 0.26$, time, $F(1, 57) = 49.05$, $p < .001$, $\eta^2 = 0.78$, and a group by test interaction effect, $F(2, 57) = 7.16$, $p < .002$, $\eta^2 = 0.20$. These results reflect the different performance outcomes reported above. Importantly, there were no time interaction effects with group or test. Finally, no sex differences were identified for physical performance or pacing.

A series of 3 group by 2 sex by 2 test ANOVAs on the self-report measures following the physical task (Table 2) yielded test main effects for mental fatigue, $F(1, 57) = 20.74$, $p < .001$, $\eta^2 = 0.27$, ($M_{\text{pre-test}} = 1.84 < M_{\text{post-test}} = 2.93$), mental exertion, $F(1, 57) = 6.20$, $p < .02$, $\eta^2 = 0.10$, ($M_{\text{pre-test}} = 1.90 < M_{\text{post-test}} = 2.56$), general fatigue, $F(1, 57) = 19.76$, $p < .001$, $\eta^2 = 0.26$, ($M_{\text{pre-test}} = 2.23 < M_{\text{post-test}} = 2.68$), vigor, $F(1, 57) = 4.65$, $p < .04$, $\eta^2 = 0.08$, ($M_{\text{pre-test}} = 3.08 > M_{\text{post-test}} = 2.83$), and success motivation, $F(1, 57) = 4.96$, $p < .03$, $\eta^2 = 0.08$, ($M_{\text{pre-test}} = 2.47 > M_{\text{post-test}} = 2.26$). A 3 group by 2 sex by 2 test ANOVA on perceived exertion during the physical task (Table 2) yielded a group main effect, $F(2, 57) = 9.40$, $p < .001$, $\eta^2 = 0.25$, ($M_{\text{feedback}} = 6.38 = M_{\text{no feedback}} = 5.57 > M_{\text{control}} = 4.32$), In sum, relative to the pre-test, the post-test was associated with increased mental fatigue, mental exertion, and general fatigue and with decreased vigor and success motivation. None of the group by test interactions were significant. No sex differences were identified for any measure.

4. Discussion

The current study investigated the effect of a prolonged cognitive task on mental fatigue and determined the effect of performance feedback on endurance performance and psychological processes during a physical muscular endurance task. We found evidence to fully support our first hypothesis by showing that a 20-min 2-back task increased mental fatigue and that visual performance feedback prevented the standard mental fatigue-induced impairment in endurance performance on a 5-min rhythmic muscular endurance handgrip task. However, contrary to expectation, we failed to support our second hypothesis, since performance feedback did not affect fatigue, effort, or motivation during the exercise task. Finally, our third hypothesis was not supported since we found no evidence that gender moderated these effects or that males and females differed in performance or perceptions. Our key study findings are considered below.

Our study confirmed that a 20-min memory updating task increased mental fatigue. Specifically, we found that a 20-min 2-back task increased mental fatigue and mental exertion ratings in the feedback and no feedback groups compared to control. This key finding is in line with past research showing that a 20-30-min 2-back task induced mental fatigue (Dallaway et al., 2022; Mizuno et al., 2011; Shigihara et al., 2013; Tanaka et al., 2009), In relation to the broader debate concerning the minimum cognitive task duration required to induce mental fatigue, with some advocating tasks of between 30 and 90 min (e.g., Clark et al., 2019; Duncan et al., 2015), we found, in line with other studies (DeLuca, 2005; Helton et al., 2007), that a state of mental fatigue was induced after just 20 min. Moreover, the feedback and no feedback groups also reported higher general fatigue, in agreement with some (MacMahon et al., 2014; Marcora et al., 2009) but not other research (Brownsberger et al., 2013; Smith et al., 2016).

Our first study purpose was to examine the effect of performance feedback on endurance performance. In support of our hypothesis, we found that visual performance feedback prevented the typical reduction in endurance performance on a physical task following completion of a mentally fatiguing cognitive task. This study was the first, to our knowledge, to determine the effect of visual performance feedback on mentally fatigued individuals performing a physical endurance task. We confirmed the established sequential-task phenomenon whereby a state of mental fatigue impairs endurance performance (Penna et al., 2018; Pires et al., 2018). Notably, we showed that the substantial impairment in physical endurance performance following the 2-back, which corresponded to a 14.4% drop in the no feedback group, was prevented by the provision of visual performance feedback during the physical task, which was confirmed by a trivial drop in performance of only 2.2% in the feedback group. The superior performance with performance feedback relative to no feedback when in a state of mental fatigue cannot be attributed to changes in pacing strategy. In sum, visual performance feedback mitigated the effect of mental fatigue on physical performance.

Our second study purpose was to examine the effect of performance feedback on psychological processes during the physical task. We failed to support our hypothesis: performance feedback did not influence fatigue, exertion, vigor, and motivation during the physical task. Mental fatigue can reduce effort and motivation (Herlambang et al., 2019; Van der Linden et al., 2003). For example, mentally fatigued athletes can go through the motions during tasks, and simply follow instructions rather than perform the tasks with intensity (Russel et al., 2019). We expected to see a decrease in intrinsic motivation during the physical task in mentally fatigued participants. This expectation was based, at least in part, on a study showing that intrinsic motivation was lower when mentally fatigued, despite providing participants with encouragement and feedback (Martin et al., 2015). Similar to the current null findings for motivation, previous studies have reported no differences between mentally fatigued and control groups in measures of success motivation or intrinsic motivation during physical endurance tasks (Marcora et al., 2009; Pageaux et al., 2014). The absence of group differences in motivation may be attributed to the provision of a monetary reward (Marcora et al., 2009). Indeed. there is evidence that rewards can counteract the effect of mental fatigue by restoring performance to pre-fatigue levels (Hopstaken et al., 2015). However, the current study showed that both groups who were offered a £20 monetary reward based on their performance experienced mental fatigue after completing the 2-back memory task. Notably, this state of mental fatigue impaired the performance of the no feedback group but not the feedback group. In terms of motivation, we observed no differences among the groups in either extrinsic or intrinsic motivation. The lack of group differences in motivation suggests that the impact of mental fatigue on performance was mitigated by all participants wishing to perform well. However, that every group only reported moderate levels of motivation might also suggest that the small monetary incentive was ineffective. Ratings of perceived exertion did not change from post-test to pre-test in all three groups, indicating that neither the provision of performance feedback nor the experience of mental fatigue influenced the overall gestalt sensory experience during endurance exercise. A state of mental fatigue can elevate perceived effort during exercise when performed at the same intensity (Van Cutsem et al., 2017). It is possible that this discrepancy may be attributed to differences in how participants rate exertion during exercise when instructed to perform to their best ability in a variable, relative to a fixed workload task. Importantly the feedback group were able to generate more force during the post-test than the no feedback group, with no difference in ratings of perceived exertion between the groups.

Our third study purpose was to examine whether the effects of mental fatigue and performance feedback were moderated by sex. In line with previous studies (e.g., Bray et al., 2012, 2008; Lopes et al., 2020) we found that physical performance was the same for both sexes. Importantly, we failed to find any evidence either that the negative effect of mental fatigue on performance was moderated by gender or that the mitigating effect of performance feedback on performance was moderated by gender. Taken together, these null findings argue that a state of mental fatigue can impair the sporting performance of both male and female athletes alike, and, importantly, argue that athletes of both sexes can benefit equally from the provision of performance feedback.

4.1. Practical implications

This study confirmed that mental fatigue elicited by a 20-min 2-back cognitive task impaired subsequent physical endurance performance, and, importantly showed that visual performance feedback can mitigate this effect. Accordingly, visual performance feedback can be used as an intervention in sport. For example, coaches assess their athletes mental fatigue status prior to training and competition, and training programs can be adapted to help those in a state of mental fatigue by delivering performance feedback (e.g., time pacing, distance covered, distance remaining) via smart devices (e.g., Diaz et al., 2015) to optimize performance. It is worth noting, however, that because experienced athletes are better able to maintain performance when mentally fatigued (Martin et al., 2016), any effects of mental fatigue and visual performance feedback on endurance performance may depend on the status of the athletes.

4.2. Study limitations and future directions

Our important and novel study findings should be interpreted in light of potential study limitations. First, the 2-back task, that induced mental fatigue and impaired exercise performance, does not resemble mentally fatiguing tasks (e.g., interviews, tactical meetings) that regularly occur before training and competition in sport. Therefore, studies could examine the effectiveness of our performance feedback intervention using other more ecologically valid mentally fatiguing tasks. Second, we only examined one mode of exercise – a rhythmic muscular endurance handgrip task. It would be interesting to determine whether the beneficial effect of performance feedback generalized to other modes, including whole body endurance tasks (e.g., Weavil & Amann, 2019). Third, attention was not measured. Feedback can distract attention from internal sensations (Williams et al., 2015), which contribute to overall ratings of perceived exertion (Jameson & Ring, 2000). Accordingly, attentional processes could be assessed in future studies as a mechanism underlying the effect of feedback on the fatigue-performance phenomenon. Fourth, we noted group differences in perceived exertion with the control group reporting lower exertion than the feedback and no feedback groups. Importantly, however, the absence of a test main effect suggests that all participants were willing to commit the same level of exertion during each test. Fifth, we measured mental fatigue using self-reports. Although these are typically used in this literature, it would be helpful to corroborate perceptions of mental states using neurophysiological indices, such as cortical oscillations from electroencephalographic recordings. Finally, it is worth noting that the improvements in performance associated with the provision of performance feedback were evident in both males and females, arguing for the generalizability of the phenomenon. However, to improve our understanding of sex differences in neuromuscular function and physiological fatigue (Hunter, 2014), further investigations into the effects of mental fatigue on performance should be sure to include both male and female participants.

4.3. Conclusion

The current findings suggest that simple performance feedback interventions can be used by coaches to prevent the negative performance effects associated with a state of mental fatigue. When participants were in a state of mental fatigue, those who were provided with performance feedback were able to generate more force for the same perception of exertion than those without. Applied research is needed to determine the boundary conditions (e.g., tasks) under which such interventions can help optimize performance of athletes in competitive sport.

Declaration of interest

The authors have declared no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2022.102210.

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