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Effects of isolated and combined mental and physical fatigue on motor skill and endurance exercise performance

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ABSTRACT

Background: Mental fatigue, elicited by cognitive demands, can impair sport and exercise performance. The effects of isolated mental fatigue on performance are well documented but few studies have explored the effects of combined mental and physical fatigue on skilled motor and endurance exercise performance.

Objective: This study explored the effects of isolated mental, isolated physical, and combined (mental plus physical) fatigue on skill and exercise task performance.

Method: 164 athletes were randomly assigned to 1 of 4 groups: mental fatigue, physical fatigue, combined fatigue, control (no fatigue). Mental fatigue was induced by a 15-min time-load dual-back cognitive task. Physical fatigue was induced by a 90-s burpee exercise task. Next, all participants completed a throwing skill task and performed burpee exercises to failure. Objective (brief Psychomotor Vigilance Task, PVT-B) and subjective (self-report) measures of mental fatigue and Ratings of Perceived Exertion were obtained throughout.

Results: The mental fatigue and combined fatigue groups performed the worst on both the throwing and burpee tasks compared with the physical fatigue and control groups. The former reported higher mental fatigue throughout and had worse response accuracy and variation on the end-of-session PVT-B task. The combined fatigue group performed better than the mental fatigue group on the throwing and burpee tasks.

Conclusion: A demanding cognitive task induced a state of mental fatigue and impaired skill and endurance performance. Mental fatigue alone was more detrimental than combined fatigue to skill and endurance performance, suggesting that the physical activity manipulation reduced the negative effects of mental fatigue on performance.

1. Introduction

Sport is physically and mentally demanding, with sustained periods of alertness being required by athletes who must select relevant informational cues in a dynamic environment, whilst integrating tactical elements and responding to the opposition (Díaz-García, García-Calvo, López-Gajardo, et al., 2023). Moreover, states of mental and physical fatigue are elicited by gameplay in athletes (Russell et al, 2019). Fatigue is a multifaceted concept that can impair performance. Physical (neuromuscular) fatigue is defined as a failure to maintain the required or expected force or power output (Gibson & Edwards, 1985). It is closely monitored across a season to enhance recovery and training (Halson, 2014). Mental fatigue is defined as a psychobiological state elicited by cognitive demands and is characterised by feelings of tiredness, a lack of energy, and impaired cognition (Marcora et al, 2009; Van Cutsem et al, 2017). Managing mental fatigue is recommended to facilitate performance and it is important that athlete personnel are adequately informed to identify and counter mental fatigue (Roelands et al, 2022). Despite mental and physical fatigue operating as separate but simultaneously occurring constructs (Russell et al, 2019), they have often been examined separately in relation to sporting performance which limits the application of research findings to the practical realm.

There is a growing body of research exploring the effects of mental fatigue on physical and cognitive performance (see reviews Brown et al, 2020; Russell et al, 2019). It has been found to impair endurance (Marcora et al, 2009), increase errors (Van der Linden et al, 2003), and reduce cognitive control (Lorist et al, 2005). Meta-analyses have determined small-to-medium effect sizes for the fatigue-performance relationship when using cognitive tasks to evoke mental fatigue (Brown et al, 2020; Giboin & Wolff, 2019). A state of mental fatigue has been found to impair dynamic and isometric physical performance but not maximal anaerobic performance (Brown et al, 2020). This could be

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explained by the way different types of exercise are internally paced and how cognitive fatigue acts to alter pacing. When in a state of mental fatigue, athletes may report higher ratings of perceived exertion (RPE) and effort despite no peripheral changes in musculo-energetic and cardio-respiratory factors, such as heart rate, oxygen uptake, and lactate (e.g., Marcora et al, 2009). Some (e.g., Van Cutsem et al, 2017) but not all (e.g. MacMahon et al, 2014; Smith et al, 2015) studies find higher RPE when in a state of mental fatigue. Cognitive neuroscience identifies the pre-frontal cortex, including the anterior cingulate cortex, as playing a role in the regulation of effortful control, attention, self-regulation, and decision making (de Wachter et al, 2021; Shenhav et al, 2017). Activity in this brain region has been positively correlated with perceived exertion during exercise (Williamson et al, 2001). Notably, all of these factors can contribute to mental fatigue. According to the *psychobiological model of exercise performance* (Marcora, 2008, 2019), the performer's endurance exercise performance is limited by perceived exertion rather than physiological processes, and, because mental fatigue increases perceived exertion during exercise the performer will sooner reach the point at which they stop exercising. In other words, perceived exertion is moderated by a state of mental fatigue, whereby greater mental fatigue can be expected to abbreviate the time before exercise failure. Recent studies extend the reach of this phenomenon and show that mental fatigue can impair the performance of motor skills as well endurance exercise (Habay et al, 2021). Taken together, these studies demonstrate the complexity of the neural mechanisms implicated in the fatigue-performance relationship (Ishii et al, 2014) and highlight areas that should be considered when conducting research.

Few experiments have explicitly examined the effect of combined mental plus physical fatigue on performance (e.g. Díaz-García, García-Calvo, López-Gajardo, et al., 2023; Rubio-Morales et al, 2022). A combined fatigue manipulation elicited higher mental load and fatigue than an isolated mental fatigue manipulation, suggesting that physical fatigue exacerbates the negative effects of mental fatigue (Díaz-García, García-Calvo, López-Gajardo, et al., 2023). This study tested soccer performance using the Loughborough passing and shooting test and found longer sequence times, greater speed differences, and lower point scores were observed for the combined mental and physical fatigue manipulation. This suggests combined fatigue may negatively affect skill-based tasks. Given that gameplay requires athletes to repeat similar skills for sustained periods combined with physical endurance, it can be argued that combined fatigue manipulations are more ecologically valid. A review of 11 studies found a decline in skilled performance (such as decreased accuracy and increased performance time) was evident in states of mental fatigue and this was attributed to impaired executive functions (Sun et al, 2021); the effects were more prominent in offensive skills compared with defensive when exploring athlete roles. Despite this, throwing following errorless training was not found to be affected by physical or mental fatigue (Banihosseini et al, 2023), however, this study used a small sample size ($n = 16$) and whether sufficient levels of fatigue were induced to influence performance remains unclear. Combined (physical and mental fatigue) and isolated physical fatigue manipulations have also been found to impair performance in elite volleyball players (Yu et al, 2023). This finding suggests that the cognitive load may amplify physical performance decrements. However, the study found no effect of isolated mental fatigue on performance despite a slower reaction time relative to control. The performance measures assessed were jump height, agility, and the spike shot, which may be less affected by mental fatigue due to their maximal and explosive nature. Specific skilled performance is therefore suggested to be vulnerable to mental fatigue, however, the effects of combined fatigue are less well understood. This provides a rationale to explore combined fatigue on both skilled and physical performance further.

Many studies that experimentally explore the influence of mental fatigue on subsequent sport or exercise performance have used very long, repetitive cognitive tasks (e.g., Marcora et al, 2009; Martin et al, 2014; Smith et al, 2015). It is also suggested that with these long cognitive tasks, individuals may disengage or adapt to the demands of the task and therefore, they may not always be impactful (see Dallaway et al, 2023). In contrast, shorter tasks considerably reduce the availability of mental resources (Boksem & Tops, 2008). Recent evidence notes that shorter adaptive cognitive tasks (that titrate task difficulty based on ongoing performance) can induce more mental fatigue than longer non-adaptive tasks (e.g., O'Keeffe et al., 2019). Accordingly, studies are warranted that determine the effects of high demand short duration cognitive tasks on subsequent performance. This is because the extant literature addressing the dose-response relationship between the duration of the cognitive task and subsequent sport and exercise performance has yielded mixed evidence (e.g., Brown et al, 2020; Giboin & Wolff, 2019). Low demand longer cognitive tasks, that involve prolonged effort may not be inducing mental fatigue but instead a state of 'sleepiness' or under-arousal, and these states are distinct from mental fatigue (O'Keeffe et al., 2019). Previously, the shortest cognitive task to impair full-body endurance exercise was 30 min (Pageaux et al, 2015), however, more current research suggests that this may need to be revised. Shorter tasks may also be more applicable to sporting practice and could be used to induce mental fatigue efficiently in training contexts.

Our study purposes were threefold. The first study purpose was to compare the effects of manipulations of combined mental plus physical fatigue, isolated mental fatigue, isolated physical fatigue – elicited using a short high intensity cognitive task (adaptive time load dual back for 15-min) a brief high intensity exercise task (burpees for 90 s) – and no fatigue (control) on subsequent motor skill (throwing) and exercise endurance (burpees to failure) performance. We hypothesised that task performance would be impaired by the fatigue manipulations compared to control, and that performance would be worst for the combined fatigue manipulation, followed by the two isolated fatigue manipulations, and that the control group would perform the best. The second study purpose was to determine the effects of the cognitive and exercise task manipulations on objective and subjective measures of mental fatigue. We hypothesised that mental fatigue would be higher for the combined fatigue manipulation than both isolated mental and isolated physical fatigue manipulations, which would be higher than control. Our third study purpose was to determine the effects of the exercise tasks (burpees for 90 s and burpees to failure) on perceived exertion. We hypothesised that perceived exertion would be greater for the two groups who performed burpees for 90 s compared to the two groups who rested, and, moreover, perceived exertion would be elevated for all four groups after performing burpees to failure.

2. Methods

2.1. Participants

Participants were 164 (75 males, 89 females) undergraduate sport and exercise science students recruited from a British university. All were injury free. They were advised to sleep well (at least 7 h), avoid caffeine, and avoid training in the 24 h prior to testing. The study protocol was approved by the local research ethics committee. Power calculations using GPower 3.1.9.7 (Faul et al, 2007) software indicated with a sample size of 164, the study was powered at .80 to detect significant ($p < .05$) effects for group ($f = .26$, $\eta_p^2 = .06$), and group by time ($f = .13$, $\eta_p^2 = .02$) by analysis of variance corresponding to small and small-medium effect sizes, respectively (Cohen, 1992). The group main effects are relevant for our first study purpose and associated hypotheses whereas the group by time interaction effects are relevant for our second and third study purposes and associated hypotheses. Currently, there is no meta-analytic review of studies comparing the effects of combined fatigue, isolated fatigue, and no fatigue on motor skill and endurance exercise performance to provide estimates of expected effect sizes. Nevertheless, a recent review (Brown et al, 2020) identified a small-to-medium effect of prior cognitive tasks on subsequent physical task performance. Accordingly, the current study was powered to detect comparable effects.

2.2. Experimental design

The study used an experimental design, with group (mental plus physical, mental, physical, control) as the between-participants factor and test (pre, post) as the within-participant factor. Participants were randomly allocated to one of four groups in order to manipulate the state of fatigue before the subsequent physical performance tasks: mental fatigue plus physical fatigue (group 1, $n = 39$, 51 % female), mental fatigue (group 2, $n = 36$, 50 % female), physical fatigue (group 3, $n = 45$, 51 % female), or control (group 4, $n = 44$, 62 % female). The time-load dual back (TLDB) task was used to induce mental fatigue. Burpees were used to induce physical fatigue. The state of fatigue was corroborated using the Brief Psychomotor Vigilance Test (PVT-B) and subjective ratings at two times: pre and post fatigue induction. A summary of the protocol is displayed in Figure S1 (Supplementary Materials*)*.

2.3. Tasks

Burpee task. The burpee is an exercise that begins in a standing position, transitioning into a squat thrust and performing a press up, before returning the feet into a squat position and performing a jump. It induces vigorous physiological responses, limits boredom, and requires minimal space (Gist et al, 2014). It is an intense, maximal, full body exercise that tests combined muscular endurance and cardiovascular fitness and neuromuscular fatigue values have indicated a greater full body load when compared with sprinting (Bingley et al, 2019). Participants were instructed to complete as many as they could in the time period and researchers verbally encouraged them to maintain intensity throughout.

Throwing task. The task required participants to throw a beanbag (size = 10 × 15 cm, weight = 110 g) towards a target on the floor, with the front of the target positioned at a distance of 345 cm. Performance was measured using a categorical points-based scoring system: inner circle (10 points), first ring (5 points), second ring (4 points), third ring (3 points), fourth ring (2 points), beyond outer circle but on mat (1 point), off the mat (0 points). This skewed scoring system was adopted to reward pinpoint accuracy. Numbers were also physically displayed on the target to emphasise accuracy and increase motivation to perform. A total score was created by summing the points for the 9 throws; thus, the total score could range between 0 and 90 points (Figure S2, Supplementary Materials). Throws were performed consecutively and were self-paced by participants.

PVT-B cognitive task. The PVT-B is a 3-min version of the original Psychomotor Vigilance Test that provides an objective behavioral measure of mental fatigue (cf. Díaz-García et al, 2021). The shorter versions of this task have been validated as tools for fatigue assessment (Basner et al, 2011; Díaz-García, García-Calvo, Manzano-Rodríguez, et al., 2023; Smith et al., 2019). Past research shows that a state of mental fatigue induced by demanding cognitive tasks is associated with impaired response speed, accuracy and/or variability (e.g., Daub et al, 2024; Staiano et al, 2022). Participants had to respond to a circle flashing on the screen of their smartphones as quickly and as accurately as possible. Response speed (number of responses per second), accuracy (percentage of correct responses), and variation (coefficient of variation = mean/standard deviation × 100 %) scores were used to assess cognitive performance.

TLDB cognitive task. The TLDB task was used to induce a state of mental fatigue. The task consists of a primary n-back memory updating task that alternates with a secondary number decision making task. In the 1-back task, a series of letters are presented on the screen and participants must respond with arrows to indicate if the letter was the same as the one in the previous trial (left = yes, right = no). In the decision-making task, participants had to decide whether flashing numbers were odd or even, by pressing 1 for odd and 2 for even. The task operated in adaptive mode whereby task difficulty varied with performance to maintain cognitive load (O'Keeffe et al., 2019). The inter-stimulus interval for the next block of 10 trials was shortened if performance accuracy of the current block of 10 trials was equal to or greater than 90 % correct; and was lengthened if performance accuracy of the current block of 10 trials was equal to or less than 80 % correct. Participants practiced the task the day before testing and were encouraged to engage with task to the best of their ability as their performance was being monitored. The task duration was 15 min.

Breathing task. The box breathing task required participants to pace their breathing in the following repeated sequence: inhale nasally for 4 s as a circle on the screen expanded, pause, exhale orally for 4 s as the circle contracted, pause.

The PVT-B, TLDB, and box breathing tasks were performed using the SOMA-NPT app running on a smartphone, with cognitive performance indices computed using SOMA Analytics software (https://soma-npt.ch/).

2.4. Measures

All participants were asked to report subjective ratings of mental fatigue at four time points (Figure S1) using a CR-10 rating scale ranging from 0 (no mental fatigue at all) to 10 (maximal mental fatigue). They were also asked to give ratings of perceived exertion (i.e., RPE) at two time points (Figure S1) – after the fatigue manipulations (or resting in control and mental fatigue groups) and again after completing burpees to exhaustion– using a CR-10 scale ranging from 0 (no exertion) to 10 (maximal exertion). These category ratio scales, which were based on standard guidelines (Borg, 1998), have been used to assess perceived exertion and mental fatigue in previous studies using the sequential task paradigm (e.g., Dallaway, Leo, & Ring, 2022; Dallaway, Lucas, & Ring, 2022, 2023).

2.5. Procedure

At the start of the session, all participants completed the PVT-B task and gave a subjective rating of mental fatigue. This was followed by a 15-min TLDB task (combined fatigue group, mental fatigue group) to induce mental fatigue or 15-min paced (box) breathing task (physical fatigue group, control group). Afterwards, all participants provided a rating of mental fatigue. The combined fatigue group and the physical fatigue group then completed 90 s of burpees; they were encouraged to exert themselves to induce physical fatigue. The other two groups rested. Next, all groups provided an RPE. They then performed the throwing task, followed by the burpees to failure task. The number of repetitions until failure was recorded. If a participant did not complete a repetition correctly, a researcher instructed them to stop, and the number of repetitions was recorded. Ratings of mental fatigue and exertion were provided. Finally, participants completed a PVT-B and provided a rating of mental fatigue (Figure S1).

2.6. Statistical analysis

A series of 4 group (combined fatigue, mental fatigue, physical fatigue, control) ANOVAs were performed on the measures of performance: throwing accuracy and repetitions to failure. A series of 4 group by 2 time (pre, post) ANOVAs were performed on the PVT-B measures (objective markers of mental fatigue). A 4 group by 4 time (pre, cognitive, exercise, post) ANOVA was performed on the ratings of mental fatigue (subjective marker of mental fatigue). A 4 group by 2 time (exercise, post) ANOVA was performed on the ratings of perceived exertion. Significant effects were followed by *t*-test post hoc comparisons. Partial eta squared (η_p^2) values were reported as a measure of effect size, with values of .02, .13 and .26 representing small, medium and large effects, respectively (Cohen, 1992). Significance was set at $p < .05$. Statistical analyses were run using Statistical Package for the Social Sciences

(SPSS) software.

3. Results

3.1. Motor skill and endurance exercise performance

A 4 group ANOVA yielded a group effect for accuracy in the throwing task, $F(3, 160) = 3.50$, $p = .02$, $np^2 = .062$, Figure 1A. Post hoc comparisons showed that throwing was less accurate for the mental fatigue group than both the physical fatigue group ($p < .03$) and control group ($p < .003$). Moreover, throwing was less accurate for the combined fatigue group compared with the control group ($p < .05$). No differences were found between the physical fatigue and control groups. A 4 group ANOVA generated a group effect for the number of repetitions to failure in the burpee task, $F(3, 160) = 12.65$, $p < .001$, $np^2 = .192$, Figure 1B. Post hoc comparisons confirmed that fewer burpees were performed by the combined fatigue group and mental fatigue group compared with the physical fatigue group ($p < .005$ and $p < .001$) and control group ($p < .001$ and $p < .001$). No differences were detected between the combined fatigue group and mental fatigue group or between the physical fatigue group and control group.

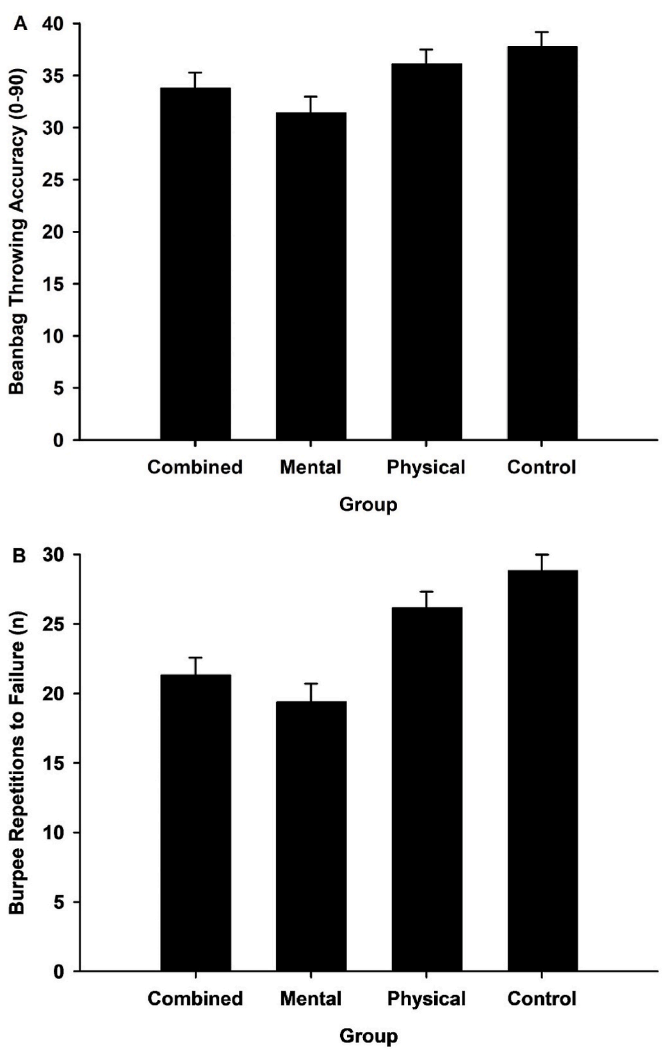

Figure 1. Mean (*SE*) performance on the beanbag throwing task (A) and burpee exercise task (B) as a function of group.

3.2. Mental fatigue

Objective behavioral measures of mental fatigue – response variation and accuracy during the PVT-B task – are depicted in Figure 2A and 2B. A series of 4 group by 2 time ANOVAs on PVT-B variation found effects for group, $F(3, 160) = 2.92$, $p = .03$, $np^2 = .052$, time, $F(1, 160) = 9.62$, $p = .002$, $np^2 = .057$, and group by time, $F(3, 160) = 2.68$, $p = .04$, $np^2 = .048$. Post hoc comparisons found no group differences at the pre assessment and some group differences at the post assessment when the mental fatigue group responded more variably than both the physical fatigue group ($p < .006$) and control group ($p < .02$) (Figure 2A). The ANOVA on PVT-B accuracy yielded a group effect, $F(3, 160) = 3.20$, $p = .03$, $np^2 = .052$. Post hoc comparisons indicated that the mental fatigue group responded less accurately than the combined fatigue group ($p < .008$), physical fatigue group ($p < .001$), and control group ($p < .02$) at the post time point, with no group differences at the pre time point (Figure 2B). The ANOVA on reaction time only generated a main time effect, $F(1, 160) = 31.01$, $p < .001$, $np^2 = .162$, with slower responses at post ($M = 276$, $SE = 2$ ms) than pre ($M = 268$, $SE = 2$ ms) time points.

The subjective rating measure of mental fatigue is depicted in Figure 2C. A 4 group by 4 time ANOVA on mental fatigue ratings yielded effects for group, $F(3, 160) = 46.42$, $p < .001$, $np^2 = .465$, time, $F(3, 158) = 211.82$, $p < .001$, $np^2 = .80$, and group by time, $F(9, 384) = 29.66$, $p < .001$, $np^2 = .348$. At the start of the session (pre time point), no group differences existed. Following the TLDB and box breathing tasks (cognitive time point), the two groups that completed the TLDB reported more mental fatigue than the two groups who performed box breathing, confirming that the manipulation successfully induced a state of mental fatigue. These group differences were maintained for the rest of the session. Following burpees to exhaustion (exercise time point) and again at the end of the session (post time point), the combined and mental fatigue groups reported more mental fatigue than the physical fatigue and control groups. Specifically, post hoc comparisons showed that the fatigue ratings of the combined and mental fatigue groups were always higher ($ps < .001$) than those of the physical fatigue and control groups at the cognitive, exercise, and post time points (Figure 2C). No differences were detected between the physical fatigue group and control group across the four time points.

3.3. Perceived exertion

Perceived exertion is displayed in Figure 3. A 4 group by 2 time ANOVA on RPE produced a group main effect, $F(3, 160) = 202.28$, $p < .001$, $np^2 = .791$, a time main effect, $F(1, 160) = 454.13$, $p < .001$, $np^2 = .739$, and a group by time interaction effect, $F(3, 160) = 143.82$, $p < .001$, $np^2 = .729$. Post hoc comparisons showed that following the 90 s burpee task manipulation (exercise time) the combined and physical fatigue groups reported higher ($ps < .001$) RPE scores than the mental fatigue and control groups. Moreover, following the burpee repetitions to exhaustion task (post time), the combined and physical fatigue groups continued to report higher RPE scores than the mental fatigue group ($p < .03$ and $p < .01$) and control group ($p < .001$ and $p < .001$). These findings confirm that the initial burpee task manipulation effectively imposed physical demands that heightened feelings of exertion, and, moreover, this manipulation continued to be felt by participants after all groups performed burpees to voluntary 'exhaustion'. Finally, at both time points no differences were found between the combined group and physical group or between the mental group and control group.

4. Discussion

The current study investigated the effects of different fatigue manipulations (combined mental plus physical, mental, and physical) on subsequent skill and endurance performance. We found evidence for the negative effects of mental fatigue, using much shorter cognitive tasks than previously used in the literature (e.g. Van Cutsem et al, 2017), on

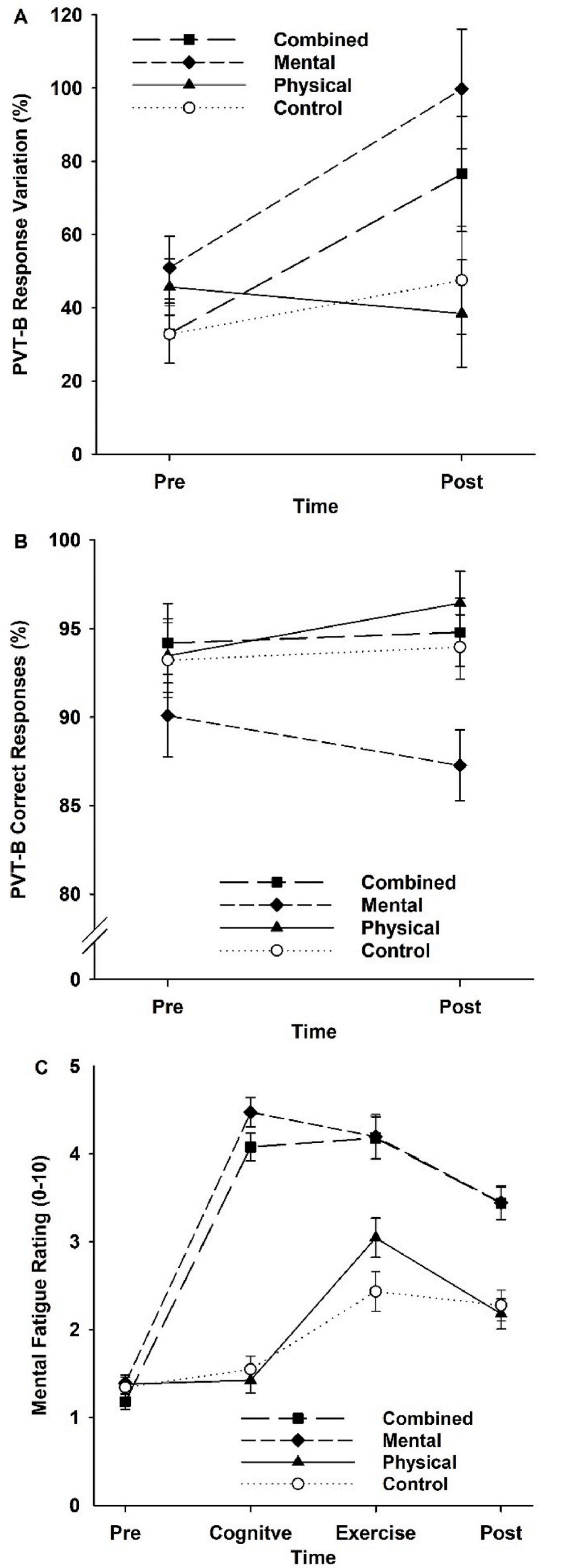

Figure 2. Mean (*SE*) response variation (A) and response accuracy (B) on the brief psychomotor vigilance task, and mental fatigue ratings (C) as a function of group and time.

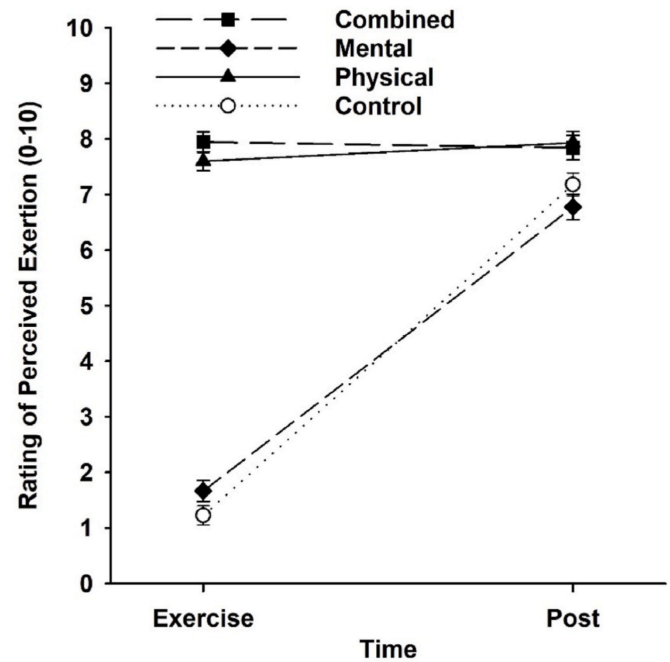

Figure 3. Mean (*SE*) ratings of perceived exertion as a function of group and time.

target throwing accuracy and exercise repetitions to failure, supporting our hypotheses. However, contrary to our expectations, combined fatigue did not exacerbate the negative effects of mental fatigue on performance, showing that, using the current tasks, adding physical fatigue did not impair performance further. As expected, we observed higher levels of subjective mental fatigue for the groups who completed the TLDB task, which in turn impacted physical performance and PVT-B performance at the end of the protocol, suggesting a lasting effect of the manipulation. The key study findings are considered below.

Our first study purpose was to explore the effects of a more cognitively demanding yet shorter task on performance. The findings confirmed that a 15-min cognitively demanding task, namely the TLDB, was effective in inducing mental fatigue both in terms of subjective ratings and objective PVT-B measures of response variation and accuracy at the end of the protocol. This supports research by Dallaway, Lucas, and Ring (2022) whereby muscular endurance was impaired in a self-paced rhythmic handgrip performance relative to control, following either a 20-min 2-back or Stroop cognitive task. The findings of these newer studies contrast the recommendations that at least 30-min tasks are needed in cognitive fatigue manipulations to negatively affect performance (see review by Van Cutsem et al, 2017). In this review, 7 out of the 11 studies used tasks that were at least 90 min long. The current study findings support the view that, with greater task loads that adapt to the performer, shorter durations are needed to elicit a state of mental fatigue (O'Keeffe et al., 2019). This suggests that the cognitive dose (i.e., task difficulty times task duration) is a more important determinant of mental fatigue than task duration. We found that a difficult 15-min TLDB, that adapted to changes in performance accuracy, evoked a state of considerably heightened mental fatigue and subsequently impaired both skill and endurance performance. These findings contrast with previous research showing that a standard 30-min Stroop task was able to induce some mental fatigue but was not able to impair subsequent throwing task performance (Banihosseini et al, 2023) or whole-body endurance task performance (Pageaux et al, 2015). In sum, these findings highlight the importance of the cognitive task dose over the cognitive task duration for eliciting mental fatigue and impairing performance.

The second study purpose was to explore the effects of fatigue manipulations on subsequent performance. Whilst mental fatigue impacted performance outcomes, physical fatigue did not exacerbate these effects. This latter finding was not expected and differs from the findings reported by Díaz-García, García-Calvo, López-Gajardo, et al. (2023). For their combined fatigue conditions, an incongruent 30-min Stroop task was used while cycling at 80–85 % of maximum heart rate. This suggests that the physical load of the current study was insufficient to create physical demands that in turn effected performance outcomes and that, going forward, exploring this further is necessary. Although the physical fatigue preload increased ratings of RPE both immediately after and following burpees to exhaustion, it did not create enough physical fatigue to hinder performance and the design of the protocol may have allowed adequate rest (and recovery) from the short physical preload. The combined group was not significantly worse than mental fatigue group and the physical fatigue group was not significantly worse than control. Burpees are a high-intensity, full body exercise and are likely to have increased feelings of exertion whilst not necessarily creating enough fatigue at the peripheral site of the muscle, for the specified duration used. High-intensity exercise can be unpleasant and exercise-induced interoceptive signals encourage the athlete to stop as a result of discomfort (Jameson and Ring (2000) and the decision to stop is likely caused by mental fatigue as opposed to physical factors which could explain the research findings here. Furthermore, it could be suggested that the short, but intense bout of physical activity might have moderated some of the negative effects of mental fatigue, explaining this difference.

Going forward, physical fatigue should be measured independently of RPE or perceived effort and the physical preload should be longer and more demanding to match the cognitive load. The results also show that whilst ratings of RPE increased in the physical and combined conditions, these groups performed better on both throwing and endurance tasks compared with those that completed the TLDB. This contrasts the work by Van Cutsem et al. (2017) and the seminal study by Marcora et al. (2009) where higher RPE ratings were found to be reported when in a state of mental fatigue but supports other research which suggests RPE is not necessarily a key determining factor (MacMahon et al, 2014; Smith et al, 2015).

The findings also show how mental fatigue builds through doing physical activity as mental fatigue measures (both subjective and objective) were higher at the end of the protocol, and even higher in the groups who completed the TLDB suggesting that physical tasks maintained or added to the levels of fatigue. This has positive implications when designing training studies or aiming to mitigate the levels of mental fatigue in sport, as these shorter tasks can create fatiguing conditions more quickly than previously suggested.

Another interpretation of the findings could be that short physical tasks may benefit performance by reducing the amount of mental fatigue. There is some evidence to suggest that cognitive warm-ups may be beneficial to both physical and cognitive performance or readiness to perform (Brewer et al, 2019). However, combined physical and cognitive warm-up protocols, especially when states of mental fatigue may be higher (due to external factors in competition), have not been explored to our knowledge. The interaction between mental and physical fatigue is an interesting area that should be explored in more detail as the combined fatigue group performed slightly better than the mental fatigue only group on both the throwing and endurance tasks.

5. Study limitations

This study provides novel evidence that shorter cognitive tasks can be used in mental fatigue protocols when exploring subsequent skill and endurance tasks and shows how combined fatigue may affect these outcomes. The findings should however be interpreted considering potential study limitations. Student athletes took part in the current study and therefore professional athletes may respond differently to both cognitive and physical preloads, as they may have developed enhanced fatigue resistance (Martin et al, 2016). It is also unclear from the findings how effective inducing physical fatigue was at impacting performance and so further research is needed to better understand this. It should be noted that this study explored sequentially induced fatigue and therefore findings may differ when fatigue is induced concurrently. Finally, further physiological measures could be taken to try to better measure effort, exertion, and physical fatigue.

6. Conclusions

The study confirmed that a 15-min TLDB task induced a state of mental fatigue that subsequently impaired skill and endurance performance. This was confirmed by the objective behavioral and subjective rating measures of mental fatigue collected at the end of the session. Being in a state of mental fatigue was not linked to higher levels of perceived exertion, suggesting that the mechanisms underpinning the findings are independent of RPE. Using a physical fatigue preload, combined fatigue did not impair performance further than mental fatigue only. This issue should be explored in more detail to better understand doses of fatigue that prevent optimal performance as ultimately fatigue, both mental and physical, arises as a consequence of engaging in sport or exercise and research can help us to understand how we can best mitigate the effects or build fatigue resistance.

Disclosure of interests

No conflicts of interests to declare.

CRediT authorship contribution statement

Hannah Mortimer: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Neil Dallaway:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Christopher Ring:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

We have no conflicts of interest to declare.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.psychsport.2024.102720.

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