Mental Fatigue Impairs Soccer-Specific Physical and Technical Performance

MITCHELL R. SMITH[1,2], AARON J. COUTTS[1], MICHELE MERLINI[3], DIETER DEPREZ[2], MATTHIEU LENOIR[2], and SAMUELE M. MARCORA[3]

[1]Sport and Exercise Discipline Group, Faculty of Health, University of Technology Sydney, AUSTRALIA; [2]Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, BELGIUM; and [3]Endurance Research Group, School of Sport and Exercise Sciences, University of Kent at Medway, UNITED KINGDOM

ABSTRACT

SMITH, M. R., A. J. COUTTS, M. MERLINI, D. DEPREZ, M. LENOIR, and S. M. MARCORA. Mental Fatigue Impairs Soccer-Specific Physical and Technical Performance. *Med. Sci. Sports Exerc.*, Vol. 48, No. 2, pp. 267–276, 2016. **Purpose**: To investigate the effects of mental fatigue on soccer-specific physical and technical performance. **Methods**: This investigation consisted of two separate studies. Study 1 assessed the soccer-specific physical performance of 12 moderately trained soccer players using the Yo-Yo Intermittent Recovery Test, Level 1 (Yo-Yo IR1). Study 2 assessed the soccer-specific technical performance of 14 experienced soccer players using the Loughborough Soccer Passing and Shooting Tests (LSPT, LSST). Each test was performed on two occasions and preceded, in a randomized, counterbalanced order, by 30 min of the Stroop task (mentally fatiguing treatment) or 30 min of reading magazines (control treatment). Subjective ratings of mental fatigue were measured before and after treatment, and mental effort and motivation were measured after treatment. Distance run, heart rate, and ratings of perceived exertion were recorded during the Yo-Yo IR1. LSPT performance time was calculated as original time plus penalty time. LSST performance was assessed using shot speed, shot accuracy, and shot sequence time. **Results**: Subjective ratings of mental fatigue and effort were higher after the Stroop task in both studies ($P < 0.001$), whereas motivation was similar between conditions. This mental fatigue significantly reduced running distance in the Yo-Yo IR1 ($P < 0.001$). No difference in heart rate existed between conditions, whereas ratings of perceived exertion were significantly higher at iso-time in the mental fatigue condition ($P < 0.01$). LSPT original time and performance time were not different between conditions; however, penalty time significantly increased in the mental fatigue condition ($P = 0.015$). Mental fatigue also impaired shot speed ($P = 0.024$) and accuracy ($P < 0.01$), whereas shot sequence time was similar between conditions. **Conclusions**: Mental fatigue impairs soccer-specific running, passing, and shooting performance. **Key Words:** COGNITIVE FATIGUE, FOOTBALL, SOCCER SKILLS, INTERMITTENT RUNNING, PERCEPTION OF EFFORT

Prolonged periods of demanding cognitive activity induce mental fatigue; a psychobiological state characterized by feelings of tiredness and lack of energy (3,23). Many studies have demonstrated the negative impact of mental fatigue on cognitive function and skilled performance in settings such as driving (3,4,16). Several investigations have also examined the effects of mental fatigue on physical performance, revealing that mental fatigue has limited influence on maximal voluntary activation and strength, explosive power, and anaerobic work capacity (24,32,37,38). In contrast, mental fatigue has been consistently shown to impair performance during self-paced (8,31) and constant load (23,32) tests of endurance. Although these investigations have identified the negative effect of mental fatigue on performance during continuous exercise, little is known about the impact of mental fatigue on physical performance in team sports that require intermittent running. Furthermore, despite many anecdotal reports in the media that mental fatigue has a negative effect on team sport performance, to the best of our knowledge, the effects of mental fatigue on technical and tactical performance in team sports have never been investigated.

One previous study investigating the demands of rugby, reported increased feelings of fatigue in players after a match (25). However, these results should be interpreted with caution as the Profile of Mood States questionnaire used to measure fatigue is not able to distinguish between symptoms of physical and mental fatigue after a match (26). Nevertheless, it is likely that a combination of physical and mental fatigue contribute to the reports of increased fatigue postmatch. Indeed, it has been suggested that team sports place significant cognitive demands on athletes as they are required to maintain concentration over prolonged periods and make fast and accurate decisions based on the retrieval and processing of information from a dynamic environment (29,41).

Address for correspondence: Mitchell Smith, Bach (Hons), Sport and Exercise Discipline Group, Faculty of Health, University of Technology Sydney, Eton Rd, Lindfield, New South Wales, Australia; E-mail: Mitchell.Smith@uts.edu.au.
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Examining changes in performance throughout a match also provides some insight into the impact of fatigue on performance in team sports. Several time-motion analysis investigations have reported general reductions in distance covered throughout a match and transient reductions in distance covered after high-intensity periods (9,27,34). Others have shown reductions in quality and quantity (9,35,36) of technical performance as matches progress. These reductions in physical and technical performance (known as match-related fatigue) are also likely to result from the combination of mental and physical fatigue induced by a match. However, it is difficult to isolate the impact of mental fatigue on team sport performance in an ecological setting as it is impractical to induce mental fatigue before competitive matches. Therefore, research must use valid and reliable tests to assess the effects of mental fatigue on factors that contribute to team sport performance.

To date however, only one study has examined the effects of mental fatigue on a factor directly associated with team sport performance: intermittent running (38). In this investigation, 10 team sport players performed a 45-min intermittent running protocol after a mentally fatiguing and control treatment. Mental fatigue reduced running velocities at low intensities, whereas high-intensity and peak sprint velocities remained similar between conditions. This study provides initial evidence that mental fatigue impairs intermittent running performance and is likely to influence player activity profiles during a match.

Although running profiles during a match partially contribute to performance in most team sports, technical aspects are also important in determining match outcome. Recently, Duncan et al. (10) reported a negative influence of mental fatigue on perceptual and motor skills of athletes. Although the tasks performed in this previous investigation were validated laboratory tests, they were not sport specific in nature, and it is unknown whether the results would directly translate into impaired team sport performance (10). Therefore, investigation into the effects of mental fatigue on sport-specific technical performance is warranted. Additional research is also required to confirm the initial finding that mental fatigue impairs intermittent running performance in team sport players (38). Therefore, in this paper, we present the findings of two related studies in soccer players. The purpose of study 1 was to investigate the effects of mental fatigue on physical performance assessed using the Yo-Yo intermittent recovery test, level 1 (Yo-Yo IR1) (14). The purpose of study 2 was to investigate the effects of mental fatigue on technical performance assessed using the Loughborough soccer passing (LSPT) and shooting (LSST) tests (1). We hypothesised that mental fatigue would impair both physical and technical performance in soccer players.

METHODS

Participants

Table 1 provides descriptive characteristics of participants from both studies. All participants were male soccer players, recruited from local soccer teams or universities and regularly participating in training and competition. Participants for study 1 were recreational players, whereas participants from study 2 were well-trained competitive players (Belgian league, divisions 2–7). All were free from medication and provided written informed consent before participation. Parental consent was provided for participants younger than 18 yr (*n* = 3; study 2), and procedures set by the university ethics committee for dealing with minors were followed. The studies' procedures were approved by the local research ethics committees of the University of Kent (study 1) and Ghent University (study 2) and follow the ethical principles for medical research involving human subjects set by the World Medical Association Declaration of Helsinki. Participation in this investigation resulted in no adverse effects. Participants were provided with written instructions outlining the studies' procedures but were not informed of their aims. Instead, participants were informed that the study was investigating the effects of reading, a common prematch activity, on heart rate during intermittent running (study 1) or technical performance (study 2).

TABLE 1. Participant characteristics.

	Study 1	Study 2
No. of participants	12	14
Age (yr)	24.0 ± 0.4	19.6 ± 3.5
Height (cm)	175.3 ± 1.3	176.7 ± 5.7
Weight (kg)	76.1 ± 2.0	67.8 ± 8.3
Playing experience (yr)	Unknown	13.6 ± 3.2

Values presented as mean ± SD.

Experimental Overview

Both studies were crossover trials. Participants visited the respective testing facilities on three separate occasions, with the first visit functioning as a familiarization session. The remaining two visits (control and mental fatigue sessions) were performed in a randomized and counterbalanced order generated by online software (randomization.com). The researchers assessing the outcome measures were blinded to treatment. Participants completed all testing sessions at the same time of day (within 1 h), separated by a minimum of 48 h. Session starting times ranged from 08:00 to 16:30, with 85% of sessions starting between 09:30 and 11:30 or 13:00 and 15:30.

Study 1. On the first visit, participants in study 1 were provided with standardized instructions for memory anchoring of Borg's 6 to 20 rating of perceived exertion (RPE) scale (5) as well as visual analogue scales (VAS) for the assessment of mental fatigue, mental effort, and motivation. Participants were also familiarized with the mentally fatiguing task (Stroop task) and the Yo-Yo IR1. Pretest instructions were provided for the upcoming testing sessions. Specifically, participants were instructed to sleep for at least 7 h, drink at least 35 mL of water per kilogram of body mass, refrain from consumption of alcohol, and avoid vigorous exercise the day before each of the following visits. Participants were also requested to avoid caffeine and nicotine

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for 3 h prior and consume a light meal 2 h before testing. Compliance with these instructions was assessed with pretest checklists upon arrival for the testing sessions. All participants reported adherence to the pretest instructions; however compliance with these instructions was not assessed using objective measures.

After completion of the pretest checklist, participants provided a subjective rating of mental fatigue using a VAS, before completing one of two 30-min reading tasks. In the control session, participants leisurely read from a selection of emotionally neutral magazines. In the mental fatigue session, participants completed a paper version of the Stroop task. Mental fatigue was again assessed after the reading task, along with mental effort and motivation. After the VAS, participants performed a 2-min running warm-up and the Yo-Yo IR1. Heart rate (HR; Polar, OY, Finland) was measured beat by beat and averaged every 5 s during the Yo-Yo IR1. HR values and RPE were recorded at the end of each level of the Yo-Yo IR1 and also at the point of exhaustion. In both conditions, participants were instructed to run until exhaustion; however, no additional motivational intervention was provided before or during the Yo-Yo IR1.

Study 2. On the first visit, participants in study 2 were provided with the same standardized instructions for the use of the VAS assessing mental fatigue, mental effort, and motivation. Participants were also familiarized with the mentally fatiguing task (Stroop task) and the LSPT and LSST. Participants performed at least two trials of the LSPT and eight shot sequences of the LSST. If after these initial trials, participants were still uncomfortable with either test, extra trials were completed until the participant and investigators were satisfied with familiarization. Participants were provided with the same pretest instructions as study 1, and compliance was ensured using a pretest checklist upon arrival for the testing sessions.

The control and mental fatigue sessions in study 2 followed the same procedures as study 1 until the point of warm-up. Study 2 involved a 3-min warm-up with a ball, incorporating passing, dribbling, and ball control elements. After warm-up, participants completed 2 trials of the LSPT; separated by a 1-min rest. After another 2-min rest, participants completed two trials of the LSST, separated by a 3-min rest. This 3-min rest comprised 2 min of passive rest, followed by 1 min of active rest with the ball. Therefore, all procedures were completed within 40 min of finishing the reading task. This study used two trials of the LSPT and LSST to provide more reliable data and extend the session to a length similar to a half soccer match. No motivational intervention was provided before or during the soccer-specific skills tests.

Treatment

Mentally fatiguing treatment. Mental fatigue was induced using a 30-min modified Stroop color-word task. The Stroop task demands response inhibition and sustained attention (20,31) and has previously been shown to induce mental fatigue (37). The Stroop task used in this investigation was a paper version of that previously used by Pageaux et al. (31). Four words (red, blue, green, and yellow) were displayed in a random order on five sheets of A4 paper with 45 words printed on each sheet. Participants were required to verbally respond to each word, with the correct response corresponding to the ink color of the word (red, blue, green, and yellow), rather than the words' meaning. Therefore, if the word "green" was printed in blue ink, the correct response was "blue." However, if the ink color of the word was red, the correct response corresponded to the meaning of the word, rather than its printed color. Therefore, if the word "green" was displayed in red ink, the correct answer was "green."

Participants' verbal responses were monitored by a member of the research team who sat with the participants throughout treatment. When an error was made, participants were required to return to the start of the current row of words and continue as normal. To increase motivation for the task, a competitive environment was created, whereby participants were challenged to successfully complete more words than the other participants within the 30-min period.

Control treatment. The control treatment involved 30 min of reading at a leisurely pace from a selection of magazines, which varied in theme, including sport, cars, and travel. Pilot testing on six individuals revealed that 30 min of reading from these magazines was emotionally neutral, according to the Brunel Mood Scale (BRUMS) (39). Participants completed both treatments in the same room, under the supervision of the same researcher.

Subjective Ratings

Subjective ratings of mental fatigue, mental effort, and motivation were scored using 100-mm VAS. The scales were anchored at one end with "none at all" and at the other end with "maximal." No other markings were displayed on the scales. Participants were asked to mark on the line the point that they felt represented their perception of their current state. The VAS score was determined by a member of the research team by measuring in millimeters from the left hand end of the line to the point that the participant marked. Mental fatigue was measured before and after treatment as a manipulation check, whereas mental effort and motivation were only measured after treatment. Mental effort referred to the reading task that had just been completed, whereas motivation referred to the upcoming soccer-specific performance tests.

Soccer-Specific Performance Tests

Yo-Yo intermittent recovery test, level 1. The Yo-Yo IR1 is a valid and reliable test of physical performance for soccer players (2,14). In a review of the Yo-Yo intermittent recovery tests, Bangsbo et al. (2) reported coefficients of variation between 4.9% and 8.7% for the Yo-Yo IR1. The test involves repeating 2 × 20-m runs (up and back = 1 bout) between cones at progressively increasing velocities. Running bouts are separated by 10 s of active recovery in which the participant walks or jogs around a cone 5 m away and returns to the starting line. Participants continue the test until they have failed to reach the finish line in time (dictated by recorded beeping sounds) on two occasions, at which point the distance covered is recorded as the test result. The Yo-Yo IR1 was completed on an indoor futsal pitch.

Loughborough soccer passing test. The LSPT and LSST were developed and validated for research purposes by Ali et al. (1) to assess soccer-specific technical performance. The layout and detailed procedures of the LSPT and LSST can be found in the validating study (1). Briefly, for the LSPT, participants were required to make 16 passes (of approximately 4 m) against standard gymnasium benches, positioned in a rectangle around the player. A colored piece of cardboard (0.6 × 0.3 m) was attached to each bench, serving as a target area, and passes were performed in one of four random color orders selected by an investigator. Participants were instructed to complete the 16 passes as fast as possible, while minimizing errors. Outcome measures for the LSPT included original time (time taken to complete all 16 passes), penalty time (time added for errors, inaccurate passes, and slow performance), and performance time (original time + penalty time). Penalty time was calculated according to the following criteria:

- +5 s for completely missing the bench or passing to the wrong bench
- +3 s for missing the target area (0.6 × 0.3 m)
- +3 s for handling the ball
- +2 s for passing the ball from outside of the passing area
- +2 s if the ball touched any cone
- +1 s for every second taken over the allocated 43 s to complete the test
- −1 s for each pass that hit the 10-cm strip in the middle of the target

The previously calculated standard errors of measurement for these outcome variables are 2, 4, and 5 s for original time, penalty time, and performance time, respectively (1).

Loughborough soccer shooting test. The LSST primarily tests soccer shooting ability but also includes passing, ball control, agility, and sprinting components. Participants began the test 20 m away from the goal line, with their back to the goal. They were required to sprint and touch one of two cones (left or right) positioned 6 m diagonally behind them. Participants then returned to the starting position and passed a ball against a bench before controlling, turning, and shooting the ball at goal. Participants then sprinted past a stationary goalkeeper to replicate following their shot in a game. Each trial was made up of 10 shots (5 with each foot), separated by 1-min rest periods. One of six random trial orders was selected for each participant.

Performance in the LSST was assessed using shot accuracy, shot speed, and shot sequence time. Shot accuracy was calculated as the mean of the total points accumulated from all shots on target. Score zones were arranged to encourage shooting toward the corners of the goal, and points were only scored if the ball struck the open space of the goal (opposite side to the goalkeeper). Time to complete each shot sequence was timed, and shot speed was estimated using high-speed (300 frames per second) video recording and video analysis software (Kinovea open source project, www.kinovea.org). Shots that were attempted from outside of the shooting area, took more than 8.5 s to complete, and/or traveled at less than 64 $km \cdot h^{-1}$ were discounted. As shot speed was assessed using 2D video analysis rather than radar technology, values should be viewed as estimates. Furthermore, shot speed data was analyzed in only 12 of the 14 participants because of poor video quality from two testing sessions. The previously calculated standard errors of measurement for these outcome variables are 0.54 points, 5.1 $km \cdot h^{-1}$, and 0.25 s for shot accuracy, shot speed, and shot sequence time, respectively (1).

Statistical Analyses

All data are presented as mean ± SD. After testing for normality, performance, HR and RPE (at exhaustion), mental effort, and motivation data were analyzed using paired samples *t* tests. HR and RPE (during Yo-Yo IR1) and mental fatigue data were analyszed using two-way (condition × time) fully repeated-measures analysis of variance. Analysis of variance for HR and RPE (during Yo-Yo IR1) data included values measured at the end of each level of the Yo-Yo IR1, up to 760 m (end of level 14). Values recorded beyond this point were excluded from analysis as players began to drop out of the test from level 14 onward. When the sphericity assumption was violated, the Greenhouse–Geisser correction was used. Significance was set at 0.05 (two-tailed) for all analyses, which were completed using SPSS (version 20; IBM, NY). Effect sizes (ES) were calculated in Microsoft Excel (Microsoft, Redmond) according to the methods suggested by Morris and DeShon (28) for investigations using repeated measures designs (equation 8).

RESULTS

Study 1

Subjective ratings. Subjective ratings of mental fatigue increased significantly after the Stroop task but not the control treatment (condition–time interaction: $F_{(1,11)}$ = 255.74, P < 0.001). Follow-up tests revealed no significant difference in subjective ratings of mental fatigue before treatment (mental fatigue: 8 ± 9 AU; control: 6 ± 8 AU; t_{11} = 1.332, P = 0.210); however, after treatment, ratings were significantly higher in the mental fatigue condition (52 ± 11 AU) compared with the control condition (12 ± 8 AU; $t(11)$ = 16.80, P < 0.001). Subjective ratings of mental effort were also higher for the Stroop task (70 ± 20 AU) than the control treatment (23 ± 20 AU; t_{11} = 10.81, P < 0.001).

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Motivation for the upcoming Yo-Yo IR1 did not differ between conditions (mental fatigue: 56 ± 21 AU; control: 58 ± 27 AU; t_{11} = 0.833, P = 0.423).

Intermittent running performance. Figure 1 displays the individual distances covered during the Yo-Yo IR1. On average, participants covered significantly shorter distances in the mental fatigue condition (1203 ± 402 m) than in the control condition (1410 ± 354 m; t_{11} = 7.194, P < 0.001, ES = 2.37). Individual distance covered was shorter in the mental fatigue condition in all 12 participants, with an average individual impairment of 16.3% ± 5.1% (95% confidence interval). No significant effects of session order existed for Yo-Yo IR1 performance (Session 1: 1310 ± 419 m; Session 2: 1302 ± 356 m; t_{11} = 0.109, P = 0.915).

Psychophysiological responses to intermittent running. No significant condition–time interactions were observed for HR or RPE; however, both HR and RPE increased over time during the Yo-Yo IR1 (HR: $F_{(2.02,\ 22.16)}$ = 888.23, P < 0.001; RPE: $F_{(1.76,\ 19.32)}$ = 233.06, P < 0.001; Fig. 2). HR was not significantly different between conditions; however, RPE at iso-time was significantly higher in the mental fatigue condition than in the control condition (main effect of condition: $F_{(1,\ 11)}$ = 43.11, P < 0.01). No significant differences in HR or RPE (range, 18–20 in both conditions) were measured at the point of exhaustion.

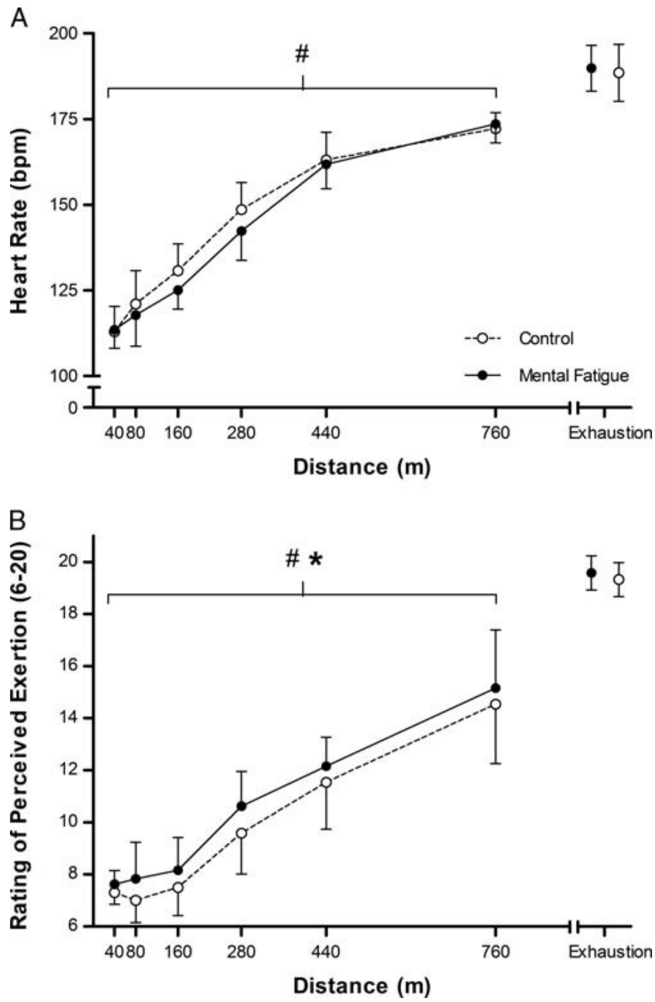

FIGURE 2—Effects of mental fatigue on psychophysiological responses to Yo-Yo Intermittent Recovery Test, Level 1. A: heart rate. B: rating of perceived exertion. #Significant main effect of time (P < 0.05). *Significant main effect of condition (P < 0.05). Data presented as mean ± SD.

Study 2

Subjective ratings. Subjective ratings of mental fatigue increased significantly after the Stroop task but not the control treatment (condition–time interaction: $F_{(1,\ 13)}$ = 18.14, P = 0.001). Follow-up tests revealed that pretreatment subjective ratings of mental fatigue were higher in the control condition (35 ± 22 AU) than the mental fatigue condition (22 ± 11 AU; t_{13} = 2.81, P = 0.015), but posttreatment ratings of mental fatigue were significantly higher in the mental fatigue condition (58 ± 22 AU) than in the control condition (39 ± 25 AU; t_{13} = 2.77, P = 0.016). Subjective ratings of mental effort were also higher for the Stroop task (69 ± 19 AU) than the control treatment (29 ± 18 AU; t_{13} = 7.19, P < 0.001). Motivation for the upcoming LSPT and LSST did not differ between conditions (mental fatigue: 80 ± 12 AU; control: 76 ± 12 AU; t_{13} = 1.50, P = 0.159).

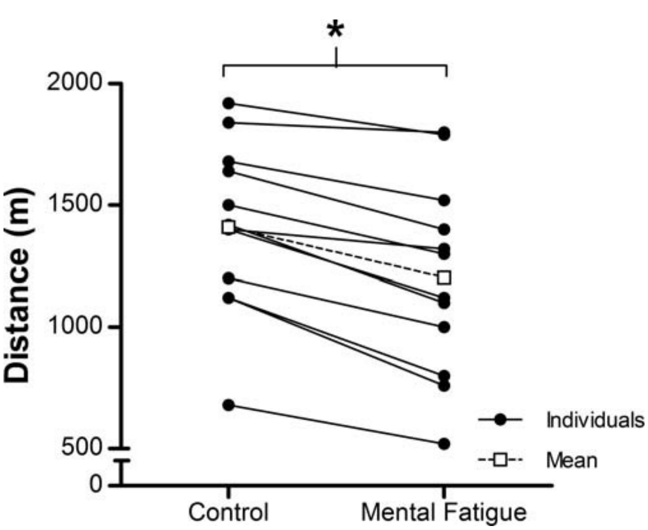

FIGURE 1—Effects of mental fatigue on Yo-Yo Intermittent Recovery Test, Level 1 performance. *Significant main effect of condition (P < 0.05).

Passing and shooting performance. A summary of the LSPT and LSST scores for both conditions is presented in Table 2. LSPT original time was not significantly different between conditions; however, penalty time was significantly higher in the mental fatigue condition than in the control condition (Fig. 3). Performance time was not significantly different between conditions. No significant effects of session order existed for original time (Session 1: 46.8 ± 5.0 s; Session 2: 48.9 ± 3.8 s; t_{13} = 1.25, P = 0.232), penalty time (Session 1: 6.5 ± 8.5 s; Session 2: 8.6 ± 6.1 s; t_{13} = 0.625,

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TABLE 2. Effects of mental fatigue on soccer-specific technical performance.

	Control	Fatigue	*t*	df	*P*	ES
LSPT						
Original time (s)	47.9 ± 4.1	47.8 ± 4.9	0.14	13	0.893	0.04
Penalty time (s)	5.2 ± 7.6	9.9 ± 6.5*	2.93	13	0.012	0.76
Performance time (s)	53.1 ± 10.5	57.7 ± 8.5	2.05	13	0.061	0.55
LSST						
Points per shot	2.0 ± 0.5	1.3 ± 0.6*	3.24	13	0.006	0.75
Shot speed (km·h^{-1})	85.0 ± 5.6	81.8 ± 4.7*	2.62	11	0.024	0.75
Shot sequence time (s)	8.0 ± 0.3	8.2 ± 0.3	1.90	13	0.080	0.48

*Significantly poorer performance than control ($P \leq 0.05$).
Values presented as mean ± SD.
ES, Effect size; LSPT, Loughborough Soccer Passing Test; LSST, Loughborough Soccer Shooting Test.

P = 0.543), or performance time (Session 1: 53.4 ± 11.1 s; Session 2: 57.5 ± 7.9 s; t_{13} = 0.955, P = 0.357).

Participants performed less accurate and slower shots on the LSST in the mental fatigue condition. Average shot sequence time tended to be slower in the mental fatigue condition, but differences were not significant. No significant effects of session order existed for shot accuracy (Session 1: 1.6 ± 0.8 points; Session 2: 1.8 ± 0.5 points; t_{13} = 0.834, P = 0.419), shot speed (Session 1: 83.7 ± 4.5 km·h^{-1}; Session 2: 83.1 ± 6.3 km·h^{-1}; t_{11} = 0.409, P = 0.691), or shot sequence time (Session 1: 8.2 ± 0.3 s; Session 2: 8.0 ± 0.3 s; t_{13} = 1.91, P = 0.079).

DISCUSSION

The current investigation used two separate studies to test the hypothesis that mental fatigue impairs soccer-specific physical and technical performance. In agreement with our hypotheses, the participants covered shorter distances during intermittent running, committed more passing and ball control errors, and performed slower and less accurate shots on goal when mentally fatigued.

Mental Fatigue, Mental Effort, and Motivation

The Stroop task requires sustained attention and response-inhibition and, when performed for prolonged periods, has been shown to induce a state of mental fatigue (37). The current results align with these previous findings, with subjective ratings of mental fatigue increasing from pre- to post-Stroop, while remaining steady in the control condition. As previously mentioned, the Stroop task used in the current study was a paper variation of that used by Pageaux et al. (31). Interestingly, Pageaux et al. (31) did not observe increased ratings of mental fatigue after the computer-based version of the Stroop task. These contrasting findings may result from the different scales used to assess fatigue or the different variation of the Stroop task used to induce mental fatigue.

In the current investigation, mental fatigue was assessed using a 100-mm VAS, whereas Pageaux et al. (31) used the fatigue subscale (score of 0–16 AU) of BRUMS (39) derived from the Profile of Mood States. It is possible that the VAS is a more sensitive measure of mental fatigue than the BRUMS. Indeed, the VAS used in this investigation provided a score range from 0 to 100 AU, specifically related to mental fatigue. In contrast, the BRUMS provides a score range from 0 to 16 AU, based on subjective feelings of tiredness (four synonymous words scored from 0 to 4 AU each). Although the BRUMS is a validated mood scale, the fatigue subscale is not specific to mental fatigue but assesses general tiredness. Furthermore, the paper version of the Stroop task may be more demanding than the computer-based version. Indeed, response inhibition is a critical component of mentally fatiguing tasks. In the paper version of the Stroop task, participants are required to audibly respond to each word, whereas in the computer version, participants are only required to press a button matching the color of the displayed word. It is likely that inhibiting the natural response to audibly read each word in the paper version is more difficult than the task of pressing a color-matched button. Nevertheless, it is clear that performing the Stroop task used in the current investigation for 30 min successfully induced mental fatigue. This finding is to be expected, considering the higher mental effort required by this demanding cognitive task compared with reading magazines at leisurely pace.

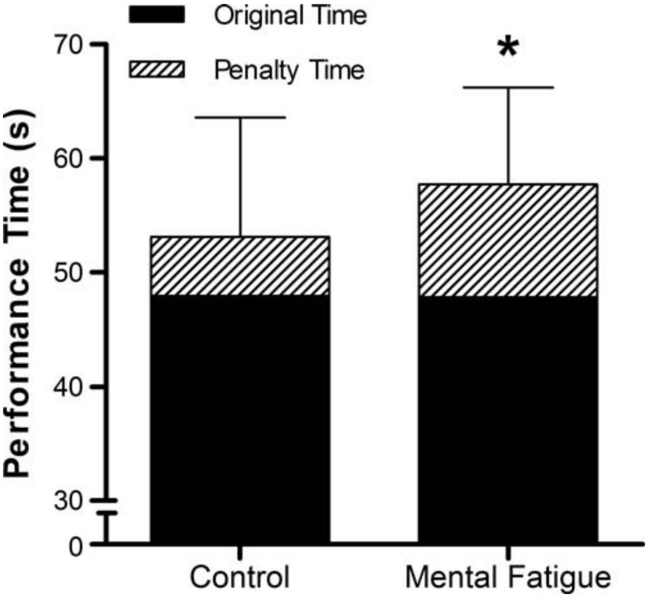

FIGURE 3—Effects of mental fatigue on Loughborough soccer passing test performance. *Significant main effect of condition for penalty time (P < 0.05). Data presented as mean ± SD.

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According to Brehm's theory (7), motivational factors play a key role in determining the maximal level of effort one is willing to exert to succeed in a particular task (i.e., potential motivation). Although no incentive was offered in the current investigation, results revealed that participants were moderately to highly motivated for the soccer-specific tests of physical and technical performance. Crucially, there was no difference in motivation between conditions. This finding is of particular interest, considering changes in motivation are strongly linked to mental fatigue (4). Furthermore, ego depletion and reward-based theories of cognitive control suggest that reductions in motivation may be responsible for performance impairments on the second of two demanding tasks (6,11). However, changes in motivation after a demanding task are likely dependent on the subsequent task to be performed. Indeed, Inzlicht et al. (13) suggest that acts of self-control lead to shifts in motivation away from "have-to" goals toward "want-to" goals. It is likely that in the current investigation, motivation was similar between conditions because participants "wanted to" perform the upcoming soccer-specific tasks. Indeed, in the current investigation, motivation was similar between conditions, suggesting that the observed physical and technical performance impairments in the mental fatigue condition must be attributed to factors other than reduced motivation. This finding is consistent with previous studies on the effects of mental fatigue on motivation related to subsequent physical tasks (23,32,38).

Effects of Mental Fatigue on Soccer-Specific Physical Performance

The purpose of study 1 was to assess the effects of mental fatigue on soccer-specific physical performance. Previously, we reported that mental fatigue impairs intermittent running performance in a test simulating the demands of team sport competitions (38). The intermittent running protocol used in the previous investigation was performed on a nonmotorized treadmill after 90 min of demanding cognitive activity. In the current investigation, we aimed to verify the previous findings using a shorter mentally fatiguing task (30 min) and a well-validated intermittent running test performed in a more natural setting (futsal field). The test used in the current investigation (Yo-Yo IR1) has previously been validated for assessing physical performance in soccer players (14) and as a measure of tolerance to incremental and intermittent running exercise. The current finding that Yo-Yo IR1 running distance was reduced after the Stroop task supports our previous findings, confirming that mental fatigue impairs soccer-specific physical performance.

In the present study, all 12 participants performed worse on the Yo-Yo IR1 when mentally fatigued, with an average individual impairment of 16.3% (207.5 m). Previous research has revealed that similar differences in Yo-Yo IR1 performance (~200 m) exist between players at different levels of competition (top elite = 2420 m; elite = 2190 m; subelite = 2030 m; moderately trained = 1810 m) (2). Furthermore, similar percentage differences in Yo-Yo IR1 performance have been observed in response to training and seasonal changes (2). Previous research has also revealed that Yo-Yo IR1 performance is significantly correlated with match running performance (2). Considering these previous findings and the very large effect size (ES = 2.37), the changes observed in this investigation have meaningful implications for soccer match performance. Indeed, it is likely that the detrimental effects of mental fatigue on Yo-Yo IR1 performance would translate to important running impairments during a soccer match.

As in previous investigations, HR increased linearly throughout the Yo-Yo IR1 in both conditions and was comparable to values recorded during soccer matches (2,15). The traditional physiological model of exercise tolerance attributes exhaustion to cardiovascular, metabolic, and/or neuromuscular factors leading to muscle fatigue (30). However, in the current investigation, HR was not significantly different between conditions at any time point. This finding aligns with those of several recent investigations, and altogether, they suggest that the negative effects of mental fatigue on exercise tolerance are not primarily mediated by changes to peripheral physiological factors associated with muscle fatigue (23,31–33,37,38).

The most likely explanation for the observed negative effect of mental fatigue on total distance run during the Yo-Yo IR1 test is that, when mentally fatigued, soccer players perceive running at a given speed more effortful. According to the psychobiological model of exercise tolerance, based on motivational intensity theory (21,22), highly motivated people stop exercise when they perceive effort to be very high or maximal. This was indeed the case in the current investigation with all soccer players reporting RPE of 18 or greater at the point of exhaustion in each condition. Furthermore, subjective ratings of motivation before exercise were not significantly different between conditions (although motivation was not assessed during the Yo-Yo IR1). This suggests that mental fatigue did not affect potential motivation, that is, the maximal effort our participants were willing to exert to succeed in the Yo-Yo IR1 test. However, RPE at iso-time was significantly higher in the mental fatigue condition.

Previous investigations have also found that mental fatigue increases RPE during subsequent exercise (23,32). As in these previous investigations, this negative effect of mental fatigue on perception of effort meant that our participants reached their maximal perceived effort and decided to stop the Yo-Yo IR1 test earlier than in the control condition, thus cumulating a shorter total distance. In the context of self-paced exercise, higher perception of effort forces participants to reduce their speed/power so that no premature exhaustion occurs, as this would have greater negative consequences on performance (8,31). A similar behavioral adjustment to compensate for higher perception of effort has been observed in our previous investigation of the effects of mental fatigue on intermittent running performance (38). Therefore, the reductions

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in speed/activity observed during soccer matches (9,27,34) may be explained, in part, by mental fatigue induced increases in perception of effort over the course of a match.

Effects of Mental Fatigue on Soccer-Specific Technical Performance

Although study 1 confirms previous findings that mental fatigue impairs soccer-specific physical performance, several other factors contribute to soccer performance and match outcome. Therefore, the purpose of study 2 was to expand the findings of study 1, by assessing the effects of mental fatigue on another important aspect of soccer match-play: technical performance of skill-based movements. As previously mentioned, reductions in quality and quantity of technical performance have been observed toward the end of a soccer match (9,35,36). This is likely in part because of an increase in physical and mental fatigue throughout a match. To the authors' knowledge, however, this is the first study to experimentally investigate the effects of mental fatigue on skill-based tests of team sport performance. Results reveal that mental fatigue impairs soccer-specific technical performance as assessed by the LSPT and LSST.

In the LSST, shot speed and accuracy were both significantly lower in the mental fatigue condition than in the control condition. Additionally, LSPT penalty time was significantly higher in the mental fatigue condition. Although not significantly different, performance time was higher in the mental fatigue condition with a moderate effect size (ES = 0.55). The increased penalty time results from a greater number of passing and ball control errors committed when mentally fatigued. These findings are not surprising as previous research has reported mental fatigue-induced increases in errors during cognitive tasks and skilled tasks such as driving (3,16) and impaired performance on perceptual and motor skills tests (10). The current study is the first to extend these findings to the context of soccer-specific technical skills. These novel findings support the hypothesis that mental fatigue contributes to the decline in technical performance observed toward the end of soccer matches.

In addition to assessing the quality of soccer-specific technical skills, the LSPT and LSST measure the length of time required to complete these skills. Interestingly, in the current investigation, mental fatigue did not affect the length of time required for players to complete either task. Indeed, both original time (LSPT) and mean shot sequence time (LSST) were not significantly different between conditions. This may be due to the time constraints of these tasks. In the LSPT overall performance is recorded as a unit of time, although in the LSST, points are not awarded when shot sequences exceed 8.5 s. Therefore, it is possible that a speed accuracy trade-off operates in the mental fatigue condition, whereby players sacrifice accuracy to complete the tasks within their respective time constraints. Lorist et al. (19) previously suggested that a similar speed–accuracy trade-off exists when mentally fatigued individuals perform cognitive tasks.

Previous research suggests that mental fatigue leads to impaired performance monitoring and inadequate performance adjustment during cognitive tasks (18). Specifically, participants performing a 120-min cognitively demanding computer task slowed reaction time in the trial immediately after an error. However, "post-error slowing" disappeared as mental fatigue increased with time-on-task (18). Therefore, in the current investigation, it is likely that when mentally fatigued, players' ability to identify errors and subsequently adjust performance was diminished. This may also further explain the finding that LSPT original time and LSST shot sequence time were not affected by mental fatigue. Indeed, "post-error slowing" may have also been absent in the mental fatigue condition of the current investigation. If after an error, players slowed down to avoid subsequent errors, it is likely that LSPT original time would have been higher in the mental fatigue condition because of this performance adjustment.

Mental fatigue also affects attentional direction and the ability to use information provided in advance to prepare for upcoming activities (3,4,19). Indeed, during cognitive tasks, mental fatigue causes a change in attention from goal-directed stimuli, toward stimuli unrelated to task performance (3). Furthermore, when mentally fatigued, participants performing cognitive computer tasks do not effectively use available cues to prepare for subsequent stimuli (4,19). Therefore, the negative effect of mental fatigue on soccer-specific technical performance may also be related to the focussing of attention on irrelevant stimuli and a reduced ability to anticipate the movement of the ball and prepare to control it. This negative impact of mental fatigue may be exacerbated in a match setting, where the addition of the crowd, advertising, and other distractions increases the number of irrelevant stimuli compared with a controlled experimental environment.

Limitations and Directions for Future Research

The current results confirm the negative impact of mental fatigue on soccer-specific physical performance and identify similar impairments to technical performance. However, this investigation does contain limitations. First, HR was the only physiological parameter measured in study 1. Therefore, it is possible that physiological mechanisms other than HR could have affected Yo-Yo IR1 performance. It is worth noting, however, that similar previous investigations have reported that various other physiological variables (blood glucose and lactate concentrations, stroke volume, cardiac output, mean arterial pressure, and minute ventilation) are unaffected by mental fatigue (23,31–33,37,38). These previous investigations support the conclusion that increased perception of effort is primarily responsible for the negative effects of mental fatigue on exercise tolerance. Future experimental research should attempt to elucidate the neurobiological mechanisms underpinning the relationship between mental fatigue and perception of effort.

The soccer-specific technical performance data of this investigation are somewhat limited by the use of 2D video analysis for shot speed. Although, this method revealed clear impairments to shot speed in mentally fatigued players, these findings should be considered an estimate. Nevertheless, this limitation to the shot speed results does not transfer to the other technical performance outcomes that were significantly impaired by mental fatigue.

Although soccer players may engage in mentally fatiguing tasks before a match, it is unlikely that any players would perform a task similar to the Stroop task before competition. Therefore, future research should identify common prematch activities, particularly those that may induce mental fatigue (e.g., tactical sessions and excessive use of smart phones, tablets, and video games), and assess whether these activities induce similar impairments to physical and technical performance. A recent study has also demonstrated that emotional regulation is mentally fatiguing and impairs physical performance (40). Because emotions are high before important soccer matches and controlling emotions has complex effects on sport performance (12), this is a very important area for future research.

Finally, the potential influence of mental fatigue on injury risk is of great importance. Recently, mental fatigue has been found to increase the chances of slips and falls and impair slip detection and recovery (17). This preliminary finding supports the need for future research on the effects of mental fatigue on the risk of injury in sport-specific settings.

Conclusions and Practical Recommendations

This investigation, using two separate studies, demonstrates that mental fatigue impairs both physical and technical performance of soccer players. Study 1 revealed that mentally fatigued soccer players reach the point of exhaustion during the Yo-Yo IR1 test earlier than in the control condition. This impairment to physical performance seems to be mediated by the negative effect of mental fatigue on perception of effort rather than peripheral changes to the cardiovascular, metabolic, and neuromuscular factors commonly associated with exercise tolerance and muscle fatigue. Study 2 revealed that mentally fatigued soccer players maintain the ability to perform soccer-specific technical tasks within similar time constraints as in the control condition. However, when mentally fatigued, soccer players commit more passing and ball control errors and reduce both shot speed and accuracy. This multifaceted effect of mental fatigue on physical and technical performance of soccer players suggests that mental fatigue may have a very negative impact on performance during a soccer match. Therefore, we suggest that coaches and players assess their prematch activities to ensure players do not engage in tasks requiring sustained attention for 30 min or more before competition, as this may induce mental fatigue and impair performance. Furthermore, sport scientists and coaches should identify and implement strategies, such as half-time caffeine supplementation that reduce the mental fatigue induced by the high cognitive demands of playing soccer for up to 90 min.

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