Does Mental Fatigue Negatively Affect Outcomes of Functional Performance Tests?

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ABSTRACT

VERSCHUEREN, J., B. TASSIGNON, M. PROOST, A. TEUGELS, J. VAN CUTSEM, B. ROELANDS, E. VERHAGEN, and R. MEEUSEN. Does Mental Fatigue Negatively Affect Outcomes of Functional Performance Tests? *Med. Sci. Sports Exerc.*, Vol. 52, No. 9, pp. 2002–2010, 2020. **Purpose:** Mental fatigue impairs psychomotor skill performance by affecting visuomotor reaction time, accuracy, and decision-making. Recently, neurocognitive functional performance tests (FPT) that integrate these outcomes have been developed. The aim of this study was to assess the effect of mental fatigue on traditional and neurocognitive FPT in healthy adults. **Methods:** Fourteen volunteers (four women; mean ± SD age, 22 ± 1 yr; height, 176.9 ± 8.4 cm; weight, 69.7 ± 10.4 kg) participated in a randomized counterbalanced crossover design. A 100% incongruent Stroop color word test of 90 min was used to induce mental fatigue and the control task encompassed watching a 90-min documentary. Traditional FPT comprised a single-leg hop for distance, countermovement jump, and Y-balance test, whereas the neurocognitive FPT encompassed the reactive balance test (RBT). All FPTs were evaluated pre–post the 90-min task. Mental fatigue was assessed using the Stroop task, visual analog scale for mental fatigue, and the Eriksen–Flanker task. **Results:** Mental fatigue was successfully induced, as shown by a significant increase in visual analog scale for mental fatigue ($P < 0.001$), with no decrease in performance on the Stroop and Eriksen–Flanker task. No interaction effect of mental fatigue was found for the Y-balance test, single-leg hop, and countermovement jump. For the RBT accuracy, a significant interaction effect of mental fatigue and time was observed ($P = 0.024$), with participants performing significantly worse when mentally fatigued. No interaction effect or main effect of condition and time was observed when considering the effect of mental fatigue on visuomotor reaction time in the RBT. **Conclusions:** Mental fatigue negatively affects a neurocognitive FPT, indicated by a decreased accuracy in response to visual stimuli in the RBT. Traditional FPT remained unaffected by mental fatigue.
Key Words: BALANCE, ACCURACY, NEUROCOGNITION, COGNITIVE DEMAND, COGNITIVE FATIGUE, INJURY PREVENTION

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In clinical practice, functional performance tests (FPT) are often used to determine an athlete's injury risk profile, rehabilitation progress, or readiness to return to play. Although FPT outcomes cannot predict injury or athletic performance, they can be associated with injury risk or performance outcomes (e.g., sprint speed) (1). Therefore, FPT outcomes are considered within a more global approach of data monitoring and pattern recognition and should be both clinician friendly and have a proximate relation to the athletic context (2,3). Clinicians cannot rely on a single test outcome or previously demonstrated association, but need to deliberately choose appropriate functional tests. However, traditional FPT often lacks proximation to the athletic context, where among other factors, the development of fatigue and an athlete's adaptability are important denominators of performance and injury risk (4). This has led to a continuous development of FPT, either by developing new neurocognitive functional tests that integrate environment perception and decision-making, or by critically reviewing the relationship of functional test outcomes with fatigue (5–8). When considering FPT within the context of fatigue, physical fatigue is known to negatively affect FPT outcomes within the concepts of proprioception (9,10), balance and postural control (11,12), strength (13,14), and hop testing (15,16). Consequently, fatigue has been hypothesized to affect an athlete's injury risk profile (17,18). Nevertheless, fatigue is a multidimensional phenomenon and the effect on FPT outcomes or injury risk profiles cannot be reduced to insights of physical fatigue (7,8). Besides physical fatigue, mental fatigue has been proposed as an important aspect of the fatigue spectrum (19,20).

Mental fatigue represents a psychobiological state caused by prolonged cognitive activity and has implications for the

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athletic context (19). In general, both athletes and staff of elite sporting organizations acknowledge that mental fatigue negatively affects performance (21). Athletes indicate that they experience mental fatigue by the large travel burdens, lack of sleep, or perturbations of day/night rhythm (22). They also indicate that trouble within the personal or social atmosphere can contribute to the feeling of mental fatigue. Mental fatigue is mainly known to impair endurance performance, visuomotor skills, reaction time, and decision-making (19). In a clinical context, the effects of mental fatigue on FPT remain unknown. Research by Lew and Qu (23) demonstrated that mental fatigue can affect balance ability in relation to the detection of slips when walking. However, Martin et al. (24) demonstrated that mental fatigue does not affect anaerobic test performance, but they did not include FPT that incorporates decision-making and coupled visuomotor reaction. The observed effects of mental fatigue on visuomotor skills (25), reaction time (26), and decision-making (27) are currently not included in traditional FPT, but could become apparent in neurocognitive FPT that evaluates adaptability. Adaptability is defined as the ability to effectively modify responses under a broad spectrum of conditions, which puts forward the importance of environmental perception and visuomotor responses (4). In a mentally fatigued state, it is possible that the athlete is not selecting the most appropriate action in response to environmental stimuli or responds slower to these stimuli. To date, it is not known whether mental fatigue impairs traditional FPT outcomes that are often used in clinical practice and neurocognitive FPT outcomes that are proposed within the concept of adaptability.

Therefore, this study aimed to assess 1) the effect of mental fatigue on traditional lower extremity FPT in healthy adults and 2) whether the effects of mental fatigue can be translated to a decreased athlete adaptability as measured with a neurocognitive FPT. We hypothesized that mental fatigue would not affect traditional FPT outcomes in accordance to the results of Martin et al., but could possibly decrease an athlete's adaptability by means of a slower visuomotor reaction time (VMRT) and diminished ability for decision-making and visuomotor skill execution.

MATERIALS AND METHODS

Participants

An *a priori* sample size calculation based on the results reported in the study by Van Cutsem et al. (28) (reported partial η^2 effect size of mental fatigue on visuomotor task ($\eta^2 = 0.197$) showed that a total of 11 participants are needed to observe the effect of mental fatigue on sport-specific visuomotor tasks. Fourteen healthy participants (4 female and 10 male; mean ± SD: age, 22 ± 1 yr; height, 176.9 ± 8.4 cm; weight, 69.7 ± 10.4 kg; body mass index, 22.2 ± 2.4; physical activity, 3322.9 ± 688.3 MET·min·wk^{-1}) participated in this study. All participants provided written informed consent before the study. Participants were blinded for the specific aims and fatigue hypotheses, and the informed consent stated that the aim of the study was to assess the difference between two cognitive tasks on FPT performance. It was only upon completion of the study that participants were informed about the real goals and hypotheses. Participants were included if they did not sustain a musculoskeletal injury in the past 6 months before the experiment. Participants had to fulfill the following criteria for all trials: (a) abstinence from heavy physical effort 24 h before the trials, (b) no consumption of caffeine-containing beverages 24 h before and during the trials, (c) no alcohol consumptions 24 h before the trials, (d) consumption of the same meal before the trials, and (e) no use of medication. These criteria were assessed with a pretrial checklist before each trial. The experimental protocol and procedures were approved by the Medical Ethics Committee of the UZ Brussel and research council of the Vrije Universiteit Brussel, Belgium (B.U.N. 143201836625). The study protocol was also registered and released on ClinicalTrials.gov Protocol Registration and Result System (NCT03643406).

Experimental Protocol

A randomized counterbalanced crossover design was used. Participants visited the laboratory on three separate occasions. The first trial consisted of a familiarization trial, whereas the following two trials consisted of a control and an experimental trial. The order of the experimental and control trial was determined by using a random number generator. All trials took place at the same time of day (8:00 AM or 10:30 AM) and were separated by at least 1 wk to guarantee full recovery. At the familiarization trial, participants' demographics (i.e., age, height, weight, leg dominance) were gathered and participants were instructed on the proper execution of the FPT. Four FPTs were selected for this experiment: 1) the countermovement jump (CMJ) test as previously utilized by Martin et al. in mental fatigue research, (2) a single-leg hop (SLH) for distance test, (3) a Y-balance test (YBT) because they are linked to the occurrence of lower extremity injuries (29,30), and (4) the reactive balance test (RBT) as a neurocognitive FPT that evaluates adaptability. The choice for the SLH test, YBT, and RBT was further substantiated by the fact that they are single-leg FPT stressing the balance system, which, according to Lew and Qu (23) can be affected by mental fatigue. In addition to this rationale, the YBT and SLH test are commonly used in clinical practice (2). To instruct upon proper performance and to account for possible learning effects on the FPT, participants performed a minimum of six repetitions of the FPT during the familiarization trial. Afterward, participants familiarized themselves with the Stroop task. They performed a progressive Stroop task with decreasing interstimulus times, which continued until participants failed to reach 80% response accuracy (i.e., 1500, 1100, 900, and 750 ms). Participants could also select a documentary of their choice to avoid boredom and ensure mental engagement during the control trial. Participants were able to choose between different documentaries: "Planet Earth: as You Have Never Seen It

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Before (The Complete Series)," "Eyewitnesses" (Volcanoes, Sharks, Dogs, Apes), or "Best of Discovery Channel" (When We Left Earth—The NASA Missions).

The experimental and control trials were designed identically (Fig. 1). All trials lasted about 2 h. Participants registered before each trial started, completed the pretrial checklist, motivation scale (31), and the visual analog scale for mental fatigue (M-VAS). Next, participants performed the first FPT session. They completed three SLH on the dominant leg and three double-leg CMJ, followed by the YBT and RBT. Functional test protocols are detailed in the functional performance section. For the second FPT session, the order was inversed starting with the RBT and YBT, followed by the CMJ and SLH. The order was fixed to maximize an efficient test progression after the fatigue intervention and account for a possible order effect, and fixed according to the fatigue hypotheses, prioritizing the RBT and YBT. Given the previous insights by Martin et al., we selected the CMJ in order to have one direct comparable outcome measure and to be able to verify whether the same result was obtained for the CMJ. Immediately after the first FPT session, participants had to indicate the perceived physical exertion using the session Rated Perceived Exertion Scale (session RPE) and the perceived mental fatigue using the visual analog scale for mental fatigue. Subsequently, participants completed a 3-min Eriksen–Flanker task before starting the experimental or control task.

The experimental task consisted of a 90-min 100% incongruent Stroop color word test, whereas the control task included watching a 90-min documentary. During the Stroop task or watching the documentary, a member of the research team was sitting behind the participant to supervise the subject and promote task engagement. Immediately after the experimental or control task, the Eriksen–Flanker task was conducted again, the perceived mental fatigue was scored, and within 60 s, subjects started performing the second FPT session. After the FPT session, participants had to rate their perceived mental fatigue and physical exertion again, followed by the National Aeronautics and Space Administration Task Load Index (NASA-TLX) for subjective workload. A detailed overview of the protocol is presented in Figure 1.

Outcome Measures

Functional performance tests. ***SLH for distance.*** The participant was instructed to jump as far as possible on the dominant leg without restriction for the arms and with a controlled landing on one leg. A controlled landing was considered as a landing without loss of balance. Only the distance of successful jumps was measured using tape measure and was written down. Participants had to complete three successful SLH both at the beginning and at the end of the trial.

Countermovement jump. The CMJ was conducted as described by Laffaye et al. (32). Participants were instructed to jump as high as possible. The Optojump Next™ (Microgate, Bolzano, Italy) was used to measure jump height. Outcome measure of the CMJ was maximal jump height as indicated by the Optojump Next™. If a certain jump technique was chosen by the participant, the same technique had to be used during all following trials. Participants completed three CMJ both at the beginning and at the end of the trial.

Y-balance test. The YBT was conducted using a Y-Balance Test Kit™ from Functional Movement Systems (FMS, Vienna, VA). Participants had to push reach indicators along three axes (anterior, posteromedial, and posterolateral) as far as possible, while maintaining balance on their dominant leg. All instructions were adopted according to Plisky et al. (33) but with the hands resting on the hips. Outcome measures of the YBT were the maximal reach distances along each axis and were noted by a researcher. Participants executed this test four times both at the beginning and at the end of the trial.

Reactive balance test. The RBT was conducted using the Y-Balance Test Kit™ in combination with LED lights (Fitlights™; FITLIGHT Sports Corp., Aurora, Ontario, Canada) that were placed along the three axes of the Y-Balance Test Kit™. Each LED light had to be extinguished 15 times (total, 45 stimuli). The order of stimuli presentation of these LED lights was randomized. Participants had to react as fast as possible to extinguish the illuminated LED light by passing over the sensor of the LED light with their foot, while maintaining balance on their dominant leg. Outcome measures of the RBT are accuracy and VMRT. VMRT was automatically saved on a tablet. Concerning accuracy, participants were

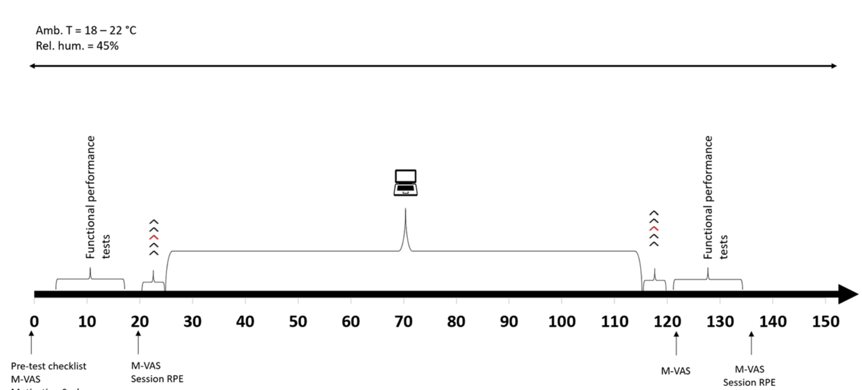

FIGURE 1—Overview of the test protocol. , 90-min Stroop task or documentary; , Eriksen–Flanker task.

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filmed while performing the RBT in order to adequately evaluate missed stimuli, multiple attempts, and decision errors retrospectively. These errors were taken into account for both VMRT and accuracy. The exact RBT test protocol, as well as definitions for missed stimuli, multiple attempts, and decision errors, was extracted from the original test reference (5). Accuracy was calculated as: "Total number of stimuli − (missed stimuli + multiple attempts needed + decision errors))/100." A missed stimulus is defined as "participant failed to extinguish LED light." Multiple attempts are defined as "reaching from standardized position, but failed to extinguish the LED light from the first time," and a decision error is defined as "initiating movement in wrong direction." VMRT was registered with the LED-Fitlight software™ on the tablet.

Cognitive Tasks

Mental fatiguing protocol: 90-min Stroop task. A 100% incongruent Stroop color word test of 90 min was used to induce mental fatigue (34,35). The Stroop task was performed on a random computer-based program, with all word–color combinations being equally represented. This task contains four words ("red," "yellow," "blue," and "green"), as well as four colors (red, yellow, blue, and green). The task was 100% incongruent, meaning the color never matched the written word. Participants were instructed to react as fast and accurate as possible to the meaning of the word when the stimulus was presented in the color red, or to respond to the color when the stimulus was presented in the color yellow, blue, or green. For analysis, accuracy and reaction time for the blue, green, and yellow stimuli were grouped as the color stimuli and the red as meaning stimuli. The interstimulus interval varied between 1100, 1500, and 1900 ms, each interstimulus interval being equally represented. To monitor the Stroop task performance as a behavioral measure of mental fatigue, task performance was divided into eight equal blocks, with corresponding accuracy and reaction time outcome measures being calculated. During the Stroop task, a member of the research team sat behind the participant to ensure participants stayed focused on the task.

Eriksen–Flanker task. The Eriksen–Flanker task was selected to assess cognitive performance in terms of accuracy and reaction time. Participants were presented five arrows and were instructed to respond as fast and accurate as possible to the direction where the middle arrow was pointing to (i.e., left or right). The same parameters were used as described by Weng et al. (36), with the exception of that all 120 stimuli were incongruent, implicating that the middle arrow always pointed in the opposite direction of the outer arrows (e.g., > > <>>). Stimuli were presented for 200 ms on a black background with an interstimulus interval that varied between 1000, 1200, 1400, and 1600 ms. All interstimulus intervals and right and left target arrows were equally represented. Participants were instructed to respond as quick and as accurate as possible to the direction of the arrow in the middle. The total Eriksen–Flanker task duration was approximately 3 min. Accuracy and reaction time during the Eriksen–Flanker task were extracted as outcome measures.

Measuring Scales

Motivation scale by Matthews et al. Before every trial started, participants completed a scale to measure their intrinsic motivation and motivation for task success to participate in this study. For this purpose, we selected the motivation scale by Matthews et al. (31).

Mental fatigue visual analog scale. To rate the subjective feeling of mental fatigue, an M-VAS was used as described by Van Cutsem et al. (37). Participants could indicate their contemporary feeling of mental fatigue on a horizontal line segment of 10 cm. Each side of the line was indicated by an extreme feeling ranging from "no mental fatigue at all" to "completely mentally exhausted." Participant had to draw a vertical line between these ranges based on their subjective feeling on that moment. M-VAS was scored four times throughout the protocol: as a baseline measure, before and after the 90-min Stroop task, and as a follow-up measure after the second session of FPT.

Session RPE. The session RPE scale was used to rate the perceived physical exertion of the functional performance tasks. Participants could indicate how physically heavy the functional tasks felt on a scale from 0 to 10. Participants had to complete the session RPE scale twice, always immediately after each FPT session.

National Aeronautics and Space Administration Task Load Index. In order to assess the perceived workload, the NASA-TLX was completed at the end of the trial. The NASA-TLX assesses six aspects with regard to the experimental or control intervention, namely: "mental demand, physical demand, temporal demand, performance, effort and frustration" (38).

Statistical Analysis

All statistical tests were conducted using the Statistical Package for the Social Sciences, version 25 (SPSS Inc., Chicago, IL). Significance was set at 0.05, and a 95% confidence interval was used for all analyses. Data are presented as mean values and SE unless stated otherwise.

To screen the normality of the data, the Shapiro–Wilk test and visual interpretation of histograms were used. If data were not normally distributed, square root transformation was used (i.e., RBT accuracy, Eriksen–Flanker accuracy and reaction time, NASA-TLX frustration subscale, Stroop accuracy). If data were still not normally distributed after square root transformation (i.e., Eriksen–Flanker reaction time), nonparametric Wilcoxon signed rank tests were used to the original data. When data were normally distributed, a repeated-measure (RM) ANOVA was selected. When interpreting RM ANOVA statistical outcomes, sphericity was verified by the Mauchly's test and significance, *F* ratios, and effect sizes (partial η^2) were evaluated. When the assumption of sphericity was not met (<0.75), RM ANOVA outcomes were adjusted with the Greenhouse–Geiser procedure. When a significant interaction effect was shown by RM ANOVA outcomes, subsequent RM ANOVA analyses or *post hoc* paired *t*-tests were used to

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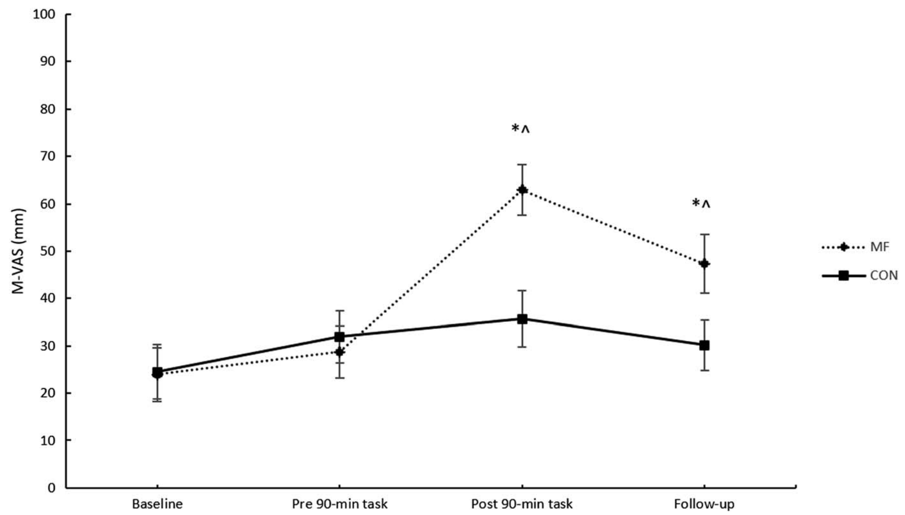

FIGURE 2—M-VAS. *Significant difference between MF and CON (P < 0.001). ^Significant difference between preintervention and postintervention (P < 0.05).

identify the effect of condition and time. When no significant interaction effect was present, the main effect of condition and time were evaluated and, if significant, further interpreted with follow-up pairwise comparisons with Bonferroni correction.

To analyze the effect of condition and time on FPT and session RPE, a (2 × 2) RM ANOVA was selected. Furthermore, paired-sample t-test was used to evaluate the effect of condition on motivation and NASA-TLX subscales. To evaluate the differences on the cognitive task performance, Stroop data were divided into eight equal blocks, and data sets for both meaning (red) and color (blue, green, and yellow) accuracy and reaction time were analyzed separately using a one-way ANOVA.

RESULTS

Markers of mental fatigue. Subjectively, participants reported higher levels of mental fatigue on the M-VAS after the 90-min Stroop task. This was identified by RM ANOVA analysis, showing an interaction effect of condition and time ($F(1.6,19.6) = 10.126$, $P = 0.002$, $\eta^2 = 0.458$). *Post hoc* paired-samples t-tests identified that subjective mental fatigue was higher in the mental fatigue group (MF) compared with the control group (CON), both after the Stroop task (P < 0.001; Fig. 2) as well as after the second set of FPT (P < 0.001; Fig. 2). Pairwise comparisons indicated that subjective mental fatigue after intervention was higher compared with baseline (P = 0.001) and preintervention (P = 0.002). At follow-up, mental fatigue was still higher compared with baseline (P = 0.019) and preintervention (P = 0.035), but significantly lower compared with immediately after the intervention (P = 0.003). All measuring scale outcomes are presented in Table 1. Stroop accuracy and reaction time data are presented in Table 2.

Within the NASA-TLX, paired-samples t-tests identified the subscales mental demand (P < 0.001), temporal demand (P = 0.012), effort (P = 0.007), and frustration (P = 0.001) to be significantly increased by the mental fatigue intervention. The session RPE as well as the perception of physical workload subscale of the NASA-TLX did not differ between conditions. Statistical analysis showed that participants' intrinsic motivation and NASA-TLX perception of task success subscale did not differ between the experimental and control conditions.

Behaviorally, Stroop accuracy, and reaction time did not differ in time throughout the 90-min Stroop task for both types of stimuli. For Eriksen–Flanker accuracy, a condition effect was observed ($F(1.0,12.0) = 16.481$, $P = 0.002$, $\eta^2 = 0.579$), and accuracy was higher in MF compared with CON. No interaction effect or time effect was observed. For Eriksen–Flanker reaction time, Wilcoxon sign ranked test did not reveal any effect for time or condition.

Functional performance tests. The acute effect of MF on FPT (SLH, CMJ, YBT, and RBT) was the primary outcome of this study. No interaction effect between condition and time was found for the YBT, SLH, or CMJ performance. A condition effect was observed for the SLH performance ($F(1.0,12.0) = 8.360$, $P = 0.014$, $\eta^2 = 0.411$) and the CMJ ($F(1.0,12.0) = 6.289$, $P = 0.028$, $\eta^2 = 0.344$). A time effect

TABLE 1. Measuring scale outcome.

Questionnaire (Part)	MF	CON
Intrinsic motivation	19.31 ± 1.00	19.38 ± 0.94
Task success motivation	16.23 ± 1.28	15.62 ± 1.40
Session RPE		
FPT session 1	3.62 ± 0.33	3.46 ± 0.29
FFPT session 2	3.77 ± 0.28	3.46 ± 0.24
M-VAS		
Baseline	24.00 ± 5.89	24.54 ± 6.03
Pre–90-min task	28.77 ± 5.70	31.92 ± 5.67
Post–90-min task	62.92 ± 5.49*,**	35.69 ± 6.10
Follow-up	47.31 ± 6.50*,**	30.15 ± 5.58
NASA TLX—mental demand	80.77 ± 3.43*	42.69 ± 4.55
NASA TLX—physical demand	36.15 ± 5.91	28.46 ± 5.47
NASA TLX—temporal demand	44.62 ± 5.17*	24.23 ± 4.56
NASA TLX—performance	47.31 ± 4.33	36.92 ± 4.44
NASA TLX—effort	64.62 ± 4.21*	45.77 ± 4.66
NASA TLX—frustration	61.54 ± 6.76*	29.23 ± 5.63

Data are presented as means ± SE.
*Significant difference between MF and CON (P < 0.001).
**Significant difference between preintervention and postintervention (P < 0.05).

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TABLE 2. Stroop ACC and RT during the 90-min Stroop task.

Block (% Completed)	RT (ms) Blue–Green–Yellow (Color)	RT (ms) Red (Meaning)	ACC (%) Blue–Green–Yellow (Color)	ACC (%) Red (Meaning)
Block 1 (12.5%)	665.87 ± 20.45	769.90 ± 22.29	90.73 ± 1.60	82.82 ± 3.19
Block 2 (25%)	677.33 ± 20.48	752.90 ± 23.41	91.09 ± 2.29	82.82 ± 4.47
Block 3 (37.5)	671.82 ± 20.98	745.55 ± 22.90	89.36 ± 3.48	84.00 ± 4.86
Block 4 (50%)	678.73 ± 21.20	740.04 ± 21.76	88.64 ± 2.96	81.27 ± 5.12
Block 5 (62.5%)	679.54 ± 21.20	745.27 ± 21.81	86.00 ± 3.16	80.45 ± 5.71
Block 6 (75%)	674.35 ± 21.19	742.68 ± 20.27	86.45 ± 3.34	78.64 ± 6.38
Block 7 (87.5%)	669.34 ± 23.11	731.53 ± 20.48	84.82 ± 3.81	76.82 ± 5.07
Block 8 (100%)	664.79 ± 22.43	726.79 ± 21.82	86.73 ± 2.21	80.00 ± 5.42

Data are presented as means ± SE.
ACC, accuracy; RT, reaction time.

was observed for the CMJ ($F(1.0,12) = 6.390$, $P = 0.027$, $\eta^2 = 0.347$). No main effects for time or condition were found for the YBT.

For the RBT accuracy, a significant interaction effect between condition and time was observed ($F(1.0,12.0) = 6.834$, $P = 0.023$, $\eta^2 = 0.363$). Follow-up *t*-tests identified that participants' accuracy was significantly lower after mental fatigue intervention compared with CON ($P = 0.012$; Table 3, Fig. 3) and compared with preintervention ($P = 0.002$; Table 3, Fig. 3). No interaction effect was observed when considering the effect of condition and time on reaction time in the RBT. In addition, no main effect of time or condition was observed for RBT reaction time.

DISCUSSION

The aim of the study was to assess whether mental fatigue affects functional test performance. This is the first study evaluating the effect of mental fatigue on FPT, including neurocognitive FPT. The results show that traditional FPT outcomes are not affected by mental fatigue, but that neurocognitive FPT outcome is negatively affected by mental fatigue. In a mentally fatigued state, the accuracy of participants on the RBT test significantly decreased. These results illustrate that mental fatigue affects an athlete's functional adaptability. Therefore, neurocognitive functional tests and their outcomes when mentally fatigued should be considered in addition to current FPT.

Manipulation check. Within our study, participants reported to be mentally fatigued after the 90-min Stroop task. This was shown by a significant increase in the M-VAS. The higher perception of mental demand coupled to the Stroop task (see NASA-TLX) might also explain the significant increase in the M-VAS.

Despite that these subjective measures indicate that mental fatigue, at least at the subjective level, was successfully induced, the 90-min Stroop task performance remained unaffected at the behavioral level. Accuracy or reaction time did not significantly deteriorate throughout the 90-min Stroop task. Although participants started responding progressively faster, while gradually making more mistakes, this did not lead to a significant decrease in accuracy or faster reaction time. Previous research has, however, shown that the 90-min 100% incongruent Stroop task is an effective intervention to induce mental fatigue (25,39) and that changes do not have to be present in all three manifestation areas (subjective, behavioral, and physiological) for mental fatigue to be present (19). Besides the Stroop performance, performance on the Eriksen–Flanker task was also followed up to check whether mental fatigue was present at the behavioral level. Also, here no behavioral marker of mental fatigue (i.e., drop in accuracy and/or increase in reaction time) was observed. Instead higher accuracy was observed in MF compared with CON. This observed main effect of condition can, however, be explained as day-to-day variability given the absence of an interaction effect. Again, these results show the need to evaluate mental fatigue within its multidimensional nature. Based on our results, we can conclude that participants did perceive the 90-min Stroop task as mentally more demanding than the control intervention and eventually also reported to experience higher mental fatigue after the Stroop task compared with after the documentary.

Are FPT affected by mental fatigue? This is the first study to evaluate the effect of mental fatigue on balance performance, hop/jump performance, and performance on a

TABLE 3. FPT outcomes.

	PRE MF	PRE CON	POST MF	POST CON
CMJ (cm)	37.78 ± 2.68	38.24 ± 2.62	36.41 ± 2.63	37.62 ± 2.89
SLH (cm)	153.14 ± 8.11	156.14 ± 8.31	150.59 ± 8.98	155.95 ± 8.70
YBT—ANT (cm)	62.93 ± 1.36	62.79 ± 1.31	63.07 ± 1.26	63.32 ± 1.30
YBT—PL (cm)	95.35 ± 2.22	95.38 ± 2.58	97.13 ± 1.56	97.87 ± 2.44
YBT—PM (cm)	99.56 ± 2.20	99.15 ± 2.41	100.33 ± 2.02	101.13 ± 2.06
RBT—VMRT (ms)	810.61 ± 38.11	819.64 ± 45.72	795.67 ± 46.49	798.08 ± 44.37
RBT—ACC (%)	91.11 ± 1.43	91.11 ± 0.73	86.16 ± 1.22*,**	91.62 ± 1.56

Data are presented as means ± SE.
*Significant difference between conditions ($P = 0.012$).
**Significant difference between PRE and POST ($P = 0.002$).
ACC, accuracy; ANT, anterior; PL, posterolateral; PM, posteromedial.

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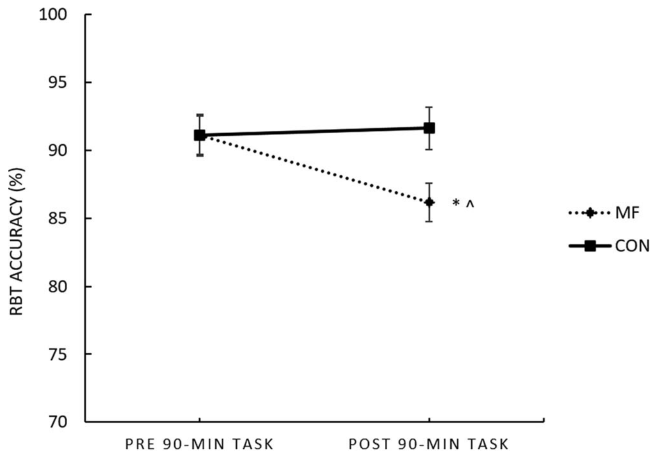

FIGURE 3—Accuracy RBT (in percent). *Significant difference between conditions ($P \leq 0.001$). ^Significant difference compared with the previous time point ($P < 0.05$).

neurocognitive balance test. In our study, mental fatigue did not affect traditional FPT (CMJ, SLH, YBT). However, a condition effect was observed for SLH and CMJ performance. In both tests, this variance can be explained by the superior performance in the control condition (Table 3), with the absolute difference between means being 4.18 cm for SLH and 0.83 cm for CMJ. The time effect for CMJ performance uncovered that mean post-CMJ performance was consistently lower than pre-CMJ performance, with the absolute difference being 0.99 cm. None of these differences exceed the SE, indicating that these time and condition effects can be considered as small. This corresponds with previous insights that mental fatigue does not affect strength or functional test performance (19,24) and was in line with our hypothesis. The main finding of our study is that mental fatigue negatively affected the accuracy of the neurocognitive RBT, which encompasses the evaluation of missed stimuli, multiple attempts, balance errors, and decision errors. This aligns with our hypothesis and previous research of Lew and Qu (23) indicating that mental fatigue can affect the detection of slips and loss of balance. Furthermore, mental fatigue has shown to affect balance ability by an increase in total postural sway in elderly with a decreased balance ability (40). In terms of participants' VMRT performance, the RBT showed no difference between the control and experimental trial, although recent findings indicate that mental fatigue negatively affects VMRT (25). However, the observed result that visuomotor reaction of the RBT did not differ when mentally fatigued, is in line with our results of the Stroop task performance, where reaction time did not differ in time throughout the 90-min Stroop task. Previous research by Gantois et al. (27) also observed a decreased accuracy without impaired reaction time. This indicates that it is not necessary for both parameters to be impaired in order for mental fatigue to negatively affect psychomotor skill performance.

One possible explanation for the discrepancy between the traditional YBT and neurocognitive RBT outcomes when mentally fatigued is that the YBT is not sensitive enough to detect the subtle impairments in balance ability caused by mental fatigue due to the preplanned nature of the test. The main difference between the RBT and the other FPT is the amount of neurocognitive signal processing and decision-making needed during the RBT. This higher load on neurocognitive signal processing pathways could explain why RBT accuracy was significantly decreased after the mental fatigue intervention. Another hypothesis that has been put forward to explain an impaired endurance performance when mentally fatigued is the altered perception of effort (19,20). We included session RPE but found no significant differences between CON and MF intervention. This can be explained by the difference in physiological stress between endurance performance and the included FPT. Motivational engagement also did not differ between CON and MF in our study. Therefore, we hypothesize that the observed effects of mental fatigue in our study could be primarily explained by altered neurocognitive signal processing during the RBT rather than altered psychological mechanisms relating to the perception of effort. Given the current state of knowledge and research, the clinical applicability of the mental fatigue effects needs to be interpreted with care. These are only the first results uncovering possible applications of neurocognitive tests. To date, it is unclear whether neurocognitive tests can be used as a decision-making tool in a clinical setting and further research is needed. Moreover, the interpretation of the decreased accuracy when mentally fatigued cannot be directly translated to the clinical context given that these first results were obtained in a laboratory setting and included a more fundamental approach to mental fatigue. Given 1) the contextual relevance of the outcome measures accuracy and VMRT (5), and 2) the insights that both athletes and staff of elite sporting organizations acknowledge that mental fatigue negatively affects performance (21), the observed decreased accuracy in a neurocognitive FPT warrants further research toward the possible link between mental fatigue and psychomotor skill performance.

In summary, mental fatigue does not affect traditional FPT outcomes but does affect the accuracy in a neurocognitive FPT. The addition of mental fatigue and neurocognitive functional tests could be considered as an added value to traditional FPT, because they expose changes in outcomes that are currently not included in the functional testing repertoire. It is possible that traditional FPT is not sensitive enough to expose the subtle impairments associated with mental fatigue. For clinicians, neurocognitive FPT could complement traditional FPT in monitoring rehabilitation progress, substantiating return to sport decision-making or injury risk profiling.

Limitations and future research. A limitation of this study is that we did not evaluate the underlying neurophysiological aspects of mental fatigue during the cognitive tasks. Previous research has also documented that mental fatigue caused by a 90-min Stroop task can affect electrophysiological changes during neurocognitive tests (37). Within the more clinically applied scope of this article and primary fatigue hypotheses, this would have been disadvantageous for the swift study progress immediately after the mental fatigue intervention. This is the first article that exposes a link between mental

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fatigue and neurocognitive FPT. Future research should focus on the neurocognitive mechanisms of mental fatigue that could further explain the decreased accuracy in the RBT. From a clinical point of view, prospective longitudinal study designs that approximate sport-specific fatigue and utilize data monitoring strategies are warranted to investigate the link of neurocognitive FPT and individual mental fatigue responses with the occurrence of sports injuries and return to play decision-making. This should be done in addition to the traditional FPT that has already shown a proximate relation to the occurrence of injuries. That way, we can strive to keep physically active people participating in sports and athlete's healthy and performing.

CONCLUSIONS

In a mentally fatigued state, participants' accuracy in response to environmental stimuli decreases, whereas traditional FPT remain unaffected. In a clinical context, neurocognitive FPT and their outcomes when mentally fatigued could be considered in addition to traditional FPT. Future studies should aim to research the underlying mechanisms by which mental fatigue affects environmental perception and decision-making, and its possible role in sports injuries. Prospective longitudinal study designs within the injury prevention, rehabilitation monitoring, or return to sport domains that include neurocognitive FPT are needed to investigate the clinical applicability and the possible relationship of these test outcomes with sports injuries. The combination of mental fatigue and neurocognitive functional tests within these domains could prove interesting.

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