Effect of Mindfulness Training on Mental Fatigue-Related Impairments of Endurance Performance and Inhibitory Control in Athletes: An Event-Related Potential Study

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ABSTRACT

Purpose: This study utilized a longitudinal design to examine the effect of mindfulness training on mental fatigue-related impairments of endurance performance and inhibitory control aspect of neurocognitive functions in athletes. **Methods**: In this randomized controlled trial (RCT) study, specifically, fifty-three aged between 18 to 25 years of college athletes were randomly assigned to either a mindfulness training group (MT, n = 26) or a waiting-list control group (WC, n = 27) after completing the pre-test. MT group engaged mindfulness program in a 60-min session per week for eight weeks, whereas WC were asked to maintain regular life and routine training. The change in dispositional mindfulness was evaluated by Athlete Mindfulness Questionnaire (AMQ) before and after the intervention. Participants completed the two 30-min manipulation conditions by Stroop task [i.e., mental fatigue condition (MF) or control condition (CON)] in both baseline and post-intervention, respectively. Before (T1) and after (T2) the 30 min manipulations, subjective mental fatigue and mood were measured using a visual analogue scale for mental fatigue (VAS-MF) and Brunel mood scale-Chinese (BRUMS-C), respectively. The participants then completed the Flanker task [i.e., reaction time (RT) and accuracy (ACC)] and its induced ERP components (i.e., N2 and P3) were recorded, and subjective mental fatigue was evaluated by VAS-MF immediately after the Flanker task (T3). Following, endurance performance [i.e., time to exhaustion (TTE] and VO2max] of participants were evaluated using graded exercise test (GXT). Additionally, VAS for motivation in task (VAS-M) was used to evaluate motivation for completing tasks after the Flanker task and GXT. **Expected results**: It was hypothesized that MT will exhibit less subjective and objective of mental fatigue, and exhibit less mental fatigue-related changes in endurance performance and inhibitory control-aspect of neurocognitive functions.

METHODS

Design and Sample

This study examining mindfulness training on mental fatigue-related impairments of endurance performance and inhibitory control aspect of neurocognitive functions in athletes was registered at ClinicalTrials.gov (NCT05452460). The actual conduct of this study was from 17/2/2022 to 10/1/2023. Initially, one hundred and twenty-five potential participants were recruited via advertisements and personal contact form several sports team in Taiwan. After screening the eligibility and participation interested, the fifty-three were included in this study, and eligible participants who were (1) regular sports training at least 4 hours weekly, (2) normal or corrected-to-normal vision, (3) right-handedness, (4) no physical limitation or injury in lower limbs before and during the study, (5) no diagnosed or self-reported neurological disorders (e.g., epilepsy), (6) no diagnosed or self-reported major psychiatric illness (e.g., major depression, schizophrenia), and (6) no major previous experience with mindfulness training.

Procedure

In this study, participants visited the lab four time, they completed the two 30-min manipulation conditions by Stroop task [i.e., mental fatigue condition (MF) or control condition (CON)] in both baseline and post-intervention, respectively. Before (T1) and after (T2) the 30 min manipulations, subjective mental fatigue and mood were measured using a visual analogue scale for mental fatigue (VAS-MF) and Brunel mood scale-Chinese (BRUMS-C), respectively. The participants then completed the Flanker task [i.e., reaction time (RT) and accuracy (ACC)] and its induced ERP components (i.e., N2 and P3) were recorded, and subjective mental fatigue was evaluated by VAS-MF immediately after the Flanker task (T3). Following, endurance performance [i.e., time to exhaustion (TTE] and VO2max] of participants were evaluated using graded exercise test (GXT). Additionally, VAS for motivation in task (VAS-M) was used to evaluate motivation for completing tasks after the Flanker task and GXT.

Prior to each visit, participants received the following instructions: do not do training vigorously the day before test, do not consume a food or beverage containing caffeine and alcohol 12 h before test, and do not sleep less than 7 h before the visit.

Outcome measures

Endurance performance assessment

The graded exercise test (GXT) on treadmill (h/p/cosmos pulsar 3p, Germany) was used to assess participant's endurance performance (i.e., VO2max and exhaustion time). Bruce protocol was adopted in the test (Bruce et al., 1973). The initial speed and grade of the GXT were set at 2.74 km/hr with grade of 10% and increases speed and grade every 3 min until

participants were voluntarily exhausted. Throughout endurance task, heart rate (HR) and perception of effort were measured every 2.5 min using an HR monitor (Polar H10, Finland) and Borg's 6-20 rating of perceived exertion (RPE)(Borg, 1982) to check whether participants meet the criteria of volitional exhaustion (Beltz et al., 2016). The time to exhaustion (TTE) and Maximum oxygen consumption (VO2max) were recorded as indicator of endurance performance.

Inhibitory control aspect of cognitive functions assessments

Followed by the manipulation conditions (i.e., 30-min Stroop task), inhibitory control was evaluated by a Flanker task (Eriksen & Eriksen, 1974; Friedman & Robbins, 2021). In the Flanker task, participants were presented with five arrows and instructed to respond as quickly and accurately as possible to the direction where the middle arrow is pointing (i.e., left or right). Types of trials are the congruent (i.e., > > > > >) and incongruent (i.e., < < > < <). The reaction time (RT) and accuracy (ACC) of incongruent trial were calculated as inhibitory control behaviors performance.

Furthermore, the neuroelectric activities during the Flanker task was measured by electroencephalographic (EEG). The EEG data was recorded from a 32-electrode Quik-Cap Neo Net (Compummedics Neuroscan Inc., Charlotte, NC, USA) based upon the Neuroscan system. Additionally, the EEGLAB (V8.3)7 and ERPLAB (V8.0)8 plugins based upon MATLAB (R2022a, Mathworks Inc.) were used to perform the offline data processing. Specifically, frontally (F3/Fz/F4) mean N2 amplitude and parietally (P3/Pz/P4) mean P3 amplitude for incongruent trial were extracted as neuroelectric marker of inhibitory control.

Manipulation check

Subjective mental fatigue assessment. Both in the baseline and post-intervention, the visual analog scale for mental fatigue (VAS-MF) was used to assess changes in perceived mental fatigue before (T1) and after (T2) two separate experimental conditions (i.e., 30-min of 100% incongruent Stroop task or 100% congruent version Stroop task), and after Flanker task (T3). The VAS has been used to extensively evaluate the change in perceived mental fatigue caused by prolonged cognitive task (Brown et al., 2020; Van Cutsem et al., 2017).

Objective mental fatigue assessment. Both in the baseline and post-intervention, participants completed either a 30-min 100% incongruent Stroop task or 30-min 100% congruent Stroop task. Accuracy in both Stroop tasks was calculated as an index of objective mental fatigue (Filipas et al., 2018; Smith et al., 2015).

Dispositional mindfulness assessment

The changes in dispositional mindfulness was assessed using the 16-items (5-Likert

scale) athlete mindfulness questionnaire (AMQ)(Zhang et al., 2017). Higher mean scores indicate a higher level of dispositional mindfulness. Changes in mindfulness total scores and subscale scores from baseline to post-intervention were examined.

Mood state assessment

The change in mood state before and after manipulation conditions was assessed using the Brunel mood scale- Chinese (BRUMS-C), which contains 23 items and divided into six respective sub-scales such as anger, confusion, depression, fatigue, tension, and vigor (Zhang et al., 2014).

Statistical Analysis Plan

Specifically, all analyses followed intent-to-treat approach. The t-test (e.g., age, training experience) or chi-square test (e.g., gender, sports) were used separately to compare the difference in demographic characteristic between groups. For the manipulation check (e.g., subjective/objective mental fatigue), a four-way mixed-design ANOVA with 2 (GROUP: MT, WC) × 2 (CONDITION: MF condition, CON condition) × 3 (ASSESSMENT TIME: T1, T2, T3) × 2 (Phase: baseline, post-intervention) was conducted to check the effect of manipulation on VAS-MF (i.e., subjective mental fatigue). A similar four-way mixed-design ANOVA with 2 (GROUP: MT, WC) × 2 (CONDITION: MF condition, CON condition) × 5 (BLOCK: B1, B2, B3, B4, B5) × 2 (Phase: baseline, post-intervention) was conducted to check the effect of manipulation on accuracy of Stroop task (i.e., objective mental fatigue). For the primary outcomes (e.g., endurance performance, inhibitory control), the condition differences (i.e., delta value) in TTE, VO2max, and RT, ACC, N2 amplitude and P3 amplitude of Flanker task between MF condition and CON condition were calculated (CON − MF). Subsequently, the post-intervention of ΔTTE, ΔVO2, ΔRT, ΔACC, ΔN2 and ΔP3 between groups were separately compared by one-way ANCOVA while controlling baseline of delta value. Furthermore, the one-way ANCOVA was also separately conducted to compare the post-intervention of AMQ scores and mental fatigue-related change of BRUMS-C scores between groups while controlling baseline of scores. All analyses were conducted using SPSS v.26 (SPSS Inc., Chicago, IL), with a significance level set at $p < 0.05$.

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