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Mindfulness and Endurance Performance in Distance Runners: The Mediator Role of Prefrontal Resting-State Activity

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Abstract

Objectives

This study examined the associations among mindfulness, endurance performance, and prefrontal cortex (PFC) resting-state activity, and explored whether PFC resting-state activity served as a neural correlate linking mindfulness to endurance performance in distance runners.

Method

Ninety-five distance runner completed the Athletic Mindfulness Questionnaire (AMQ), underwent resting-state electroencephalography (EEG), and performed a graded exercise test to determine time to exhaustion (TTE). Correlation and mediation analyses were conducted.

Results

Higher overall AMQ and awareness were associated with longer TTE (r = .231, p < .05; r = .207, p < .05); wherein higher overall AMQ is associated with lower PFC resting-state beta activity. Mediation analyses indicated indirect effects of overall AMQ scores (b = 15.84, 95% CI [1.29, 35.07]) and awareness (b = 15.60, 95% CI [1.43, 34.29]) on TTE through lower PFC resting-state beta activity.

Conclusions

Higher mindfulness was associated with lower pre-performance PFC resting-state beta activity, which was in turn associated with better endurance performance. These findings provide preliminary support for PFC resting-state beta activity as a neural correlate linking mindfulness to endurance performance.

1. Introduction

In endurance running, athletes continuously monitor external stimuli (e.g., competitors' positions, split times, and remaining distance) and internal cues (e.g., heart rate, breathing patterns, and muscular fatigue), while dynamically integrating this information to adjust exertion levels and pacing strategies through ongoing cognitive processes (Limmeroth et al., 2024; McCormick et al., 2018). As runners approach physiological limits, they often experience pronounced discomfort sensations (e.g., breathlessness, muscle soreness, lactate accumulation) that exacerbates negative emotions and thoughts (e.g., self-doubt, worries; Limmeroth et al., 2024; McCormick et al., 2018). These negative psychological states may also redirect attention from goal-relevant cues (e.g., pace) toward threat-related sensations, further undermining the cognitive control (Eysenck et al., 2007). Additionally, reduced cognitive resources and negative psychological states may influence cognitive processes that support subsequent endurance performance (McCormick et al., 2019). Accordingly, endurance performance

requires athletes to sustain attention on performance-relevant information while minimizing distractions arising from discomfort and undesirable psychological states, which is crucial for achieving performance objectives (McCormick et al., 2019).

Mindfulness is commonly described as a moment-to-moment, nonjudgmental awareness and may function as a self-regulatory process that facilitates attention regulation, emotion regulation, and other performance-relevant processes (Bondár et al., 2024). In sport contexts, mindfulness may reduce attentional capture by internal distractions (e.g., negative emotions and worries) and promote sustained focus on task-relevant cues, thereby supporting behavioral stability and performance consistency in athletes (Josefsson et al., 2019). Higher mindfulness level has been shown to be associated with greater attentional control and emotion regulation, which in turn support athletic performance (Rogowska & Tataruch, 2024). Empirical evidence has also shown that mindfulness contributes to improved actual endurance performance. Sparks et al. (2021) reported that higher dispositional mindfulness predicted better subjective rowing performance and reduced tendencies toward excessive reinvestment. Nien et al. (2024) also reported that, athletes with higher mindfulness enhanced longer time to exhaustion under mental fatigue, whereas those with lower mindfulness were more susceptible to mental fatigue. Notably, although the relationship between mindfulness and performance has been discussed in relation to mindfulness-associated neural correlates (Bondár et al., 2024), evidence linking mindfulness to endurance performance via specific neural correlates remains unclear.

Electroencephalography (EEG) is a non-invasive method used to assess neural activity, with EEG signals commonly classified into frequency bands, including delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), sensorimotor (12–15 Hz), beta (15–30 Hz), and gamma (> 30 Hz), each of which has been associated with psychological processes relevant to endurance performance. Brownsberger et al. (2013) demonstrated that experimentally induced mental fatigue in cyclists was associated with increased prefrontal beta activity and reduced pedaling power output. This finding supports the view that the prefrontal cortex (PFC) is closely linked to endurance performance, given its central role in self-regulation and cognitive control and its active engagement during endurance tasks (Wolff et al., 2018). However, most EEG studies on endurance performance have focused on cycling, and it remains unclear whether these findings extend to endurance running, which involves greater whole-body movement. EEG acquisition during running is susceptible to motion-related artifacts and noise. Therefore, resting-state EEG has been proposed as a viable approach to examine neural correlates of subsequent performance and to index athletes' preparatory states. Rogala et al. (2020) found that resting-state beta activity was negatively correlated with shooting scores. Nevertheless, the application of resting-state EEG in endurance running research remains limited, although it may offer a valuable approach for reflecting preparatory neural states and predicting subsequent performance.

Greater mindfulness has been shown to be associated with cortex thickness and activity in brain regions-related self-regulation and emotion regulation (Treves et al., 2024). Alpha activity is typically elevated during mindfulness and may reflect internally directed attention, though not specifically prefrontal. Theta activity is also increased and is particularly linked to prefrontal functioning, as frontal-

midline theta reflects executive attention and control. In contrast, beta activity shows mixed findings, with no clear prefrontal pattern (Lomas et al., 2015). Accordingly, EEG activity in PFC region may serve as a shared neural marker linking mindfulness and endurance-performance; however, this neural correlation remains to be fully elucidated.

The present study aims to investigate the associations among mindfulness, endurance performance, and PFC resting-state EEG, and further tested whether PFC theta, alpha, and beta activity mediate the relationship between mindfulness and endurance performance. Specifically, pre-performance resting-state EEG activity (theta, alpha, and beta) was examined as a potential neural mechanism linking mindfulness to endurance performance. It was hypothesized that greater mindfulness would be associated with higher theta and alpha power and lower beta power, and that mindfulness would indirectly facilitate endurance performance through increased theta and alpha activity and decreased beta activity in PFC region.

2. Materials and method

2.1. Participants

Ninety-five distance runners were recruited in this study. All participants had experience competing at the national or international level in endurance events. This study was approved by the Research Ethics Committee of National Taiwan Normal University, Taiwan (REC number: 202112HM023).

2.2. Procedure

A cross-sectional design was employed in the present study, with all assessments completed during a single laboratory visit. At the start of the visit, participants first received a detailed explanation of the study and provided written informed consent. They then completed a demographic questionnaire and the athlete mindfulness questionnaire (AMQ). After completing the questionnaires, participants were fitted with an EEG cap, a process that took approximately 30 minutes. They were seated in a soundproof room and instructed to remain physically still and relaxed with their eyes closed while four one-minute EEG resting-state trials were recorded. Following EEG recording, the cap was removed, and participants were instructed to change clothing and warm-up in preparation for the endurance performance test. Prior to the test, participants received standardized instructions on how to safely stop the treadmill test upon reaching maximal effort.

2.3. Endurance performance

Endurance performance was assessed using a motor-driven treadmill (h/p/cosmos pulsar 3p, Germany) through a graded exercise test (GXT) following the Bruce protocol (Bruce et al., 1973). The GXT began at a speed of 2.74 km/h with a 10% incline, with both speed and grade increasing every 3 minutes until participants reached perceived exhaustion. The heart rate and rating of perceived exertion (RPE) were recorded using a Polar heart rate monitor (Sport Tester PE 3000, Polar Electro Oy, Kempele, Finland) and the Borg 6 to 20 scale (Borg, 1982), respectively. Time to exhaustion (TTE), the endurance performance

outcome, was defined as the point at which participants reached maximal effort and voluntarily stopped the task. Volitional exhaustion was confirmed when at least two of the following three criteria were met: (1) visible signs of fatigue preventing the maintenance of treadmill speed, (2) RPE > 18, or (3) HR ≥ 90% of the age-predicted maximum heart rate (HR_{max}).

2.4. Athletic mindfulness level

Athletes' mindfulness levels were assessed using athlete mindfulness questionnaire (Zhang et al., 2017). The AMQ includes three dimensions: present-moment attention (e.g., "I can easily sustain my attention on the competition"), awareness (e.g., "During training or competition, I can be immediately aware of my emotional changes"), and acceptance (e.g., "During training and competition, I can put up with unpleasant thoughts and feelings"). The AMQ consists of 16 items in total, each rated on a 5-point Likert scale. Higher scores across all dimensions indicate better mindfulness level in athletes. In the current sample, the Cronbach's α coefficients demonstrated satisfactory internal consistency, with α = .882 for the overall scale, α = .783 for the present-moment attention, α = .754 for the awareness, and α = .836 for the acceptance.

2.5. Electroencephalography

2.5.1. Recording

Electroencephalographic (EEG) signals were acquired from a 32-channel NeuroScan Quick-Cap, arranged according to the International 10–10 system. CURRY 8 software and Neuroscan SynAmps2 amplifier (Compumedics Neuroscan, USA) were used to acquired and processed data in real time. Scalp electrodes (Ag/AgCl) were referenced online midway between Cz and CPz, while AFz were served as the ground. Vertical and horizontal electrooculogram (VEOG/HEOG) channels were recorded to monitor eye movements electrodes. VEOG was placed above and below the left eye, and HEOG at the outer canthi of each eye. In practice, impedances were maintained below 10 kΩ, and data were digitized at 1000 Hz, amplified 500 times, with a 60 Hz notch filter to eliminate line noise. EEG resting-state activity was collected in four separate 1-minute trials which are more reliable measurement for the data of EEG resting-state activity while participants casually sat with eyes closed.

2.5.2. Pre-processing and analysis

All further processing was carried out offline using MATLAB R2023b and the EEGLAB toolbox (Delorme & Makeig, 2004). Raw EEG data were first re-referenced to the linked mastoids (average of M1 and M2), bandpass filter was range from 1Hz to 30 Hz (12 dB/octave roll-off) was. Kurtosis of amplitudes excessed five standard deviations from the channel mean were interpolated using spherical spline interpolation. Ocular artifacts were removed via independent component analysis (ICA). More specifically, the ICA inspected with icablinkmetrics function (Pontifex et al., 2017) to identify eye-blink components. After artifact correction, the continuous data were segmented into 2-second epochs, and epochs with exceeded ± 150 μV were discarded. For spectral analysis, each epoch was windowed with a Hanning taper to minimize spectral leakage. Fast Fourier transforms (FFT) were then computed on each

windowed epoch, yielding power spectra across frequencies. Finally, the power in the theta (4–8 Hz), alpha (8–12 Hz), and beta (15–30 Hz) was transformed using the natural logarithm (ln[μV^2]). Given the role of the PFC in endurance performance (Wolff et al., 2018). all spectral analyses were focused on PFC regions, represented by the electrode sites FP1, FP2, Fz, F3, F4, F7, F8, F11, and F12.

2.6. Statistical analysis

Descriptive statistics, including means and standard deviations, were calculated for demographic information and all variables. The internal consistency of the AMQ was assessed using Cronbach's alpha. Bivariate relationships among these variables were examined using Pearson correlation coefficients, with statistical significance set at $p < .05$. To further examine whether PFC resting-state activity served as a mediating variable between mindfulness and endurance performance, mediation analysis was performed using the PROCESS macro for SPSS Model 4 (Hayes, 2013), and was conducted only when PFC resting-state activity showed correlations with both AMQ and TTE. All were variables mean-centered before running the model, and Bias-corrected 95% confidence intervals were generated based on 5,000 bootstrap resamples (Preacher & Hayes, 2004). An indirect effect was considered statistically significant if the corresponding confidence interval did not include zero. All analyses were conducted using IBM SPSS Statistics version 30.0.

3. Results

3.1. Descriptive statistics

Table 1 presents the results of descriptive statistics (mean ± standard deviation) for the demographic information and all variables.

Table 1
Descriptive statistics (M ± SD).

Demographic information	Male	Female	Overall
Sample size (*n*)	64	31	95
Age (years)	23.09 ± 4.03	20.94 ± 2.42	22.39 ± 3.71
Sport experience (years)	5.57 ± 3.50	5.63 ± 3.30	5.59 ± 3.42
TTE (s)	929.27 ± 100.37	774.58 ± 79.27	878.79 ± 118.63
AMQ	4.13 ± 0.48	3.85 ± 0.49	4.04 ± 0.50
Attention	4.19 ± 0.55	3.89 ± 0.60	4.09 ± 0.58
Awareness	4.06 ± 0.50	3.85 ± 0.63	3.99 ± 0.55
Acceptance	4.17 ± 0.64	3.80 ± 0.67	4.05 ± 0.67
theta activity (ln[μV^2])	0.66 ± 0.62	0.92 ± 0.61	0.75 ± 0.63
alpha activity (ln[μV^2])	1.50 ± 0.88	2.01 ± 0.88	1.67 ± 0.91
beta activity (ln[μV^2])	−0.75 ± 0.50	−0.42 ± 0.39	−0.64 ± 0.49

Note. Abbreviation: TTE = Time to exhaustion; s = second; AMQ = Athlete Mindfulness Questionnaire. *M* = mean, *SD* = standard deviation. PFC resting-state activity represented as natural log transformed power [ln (μV²)].

3.2. Bivariate correlations

As shown in Table 2, TTE was positively correlated with overall AMQ scores (r = .231, p < .05), attention (r = .296, p < .01), and awareness (r = .207, p < .05), but not acceptance (r = .088, p > .05). Regarding PFC resting-state activity, theta and alpha activity were not significantly correlated with TTE, AMQ scores, or AMQ dimensions. In contrast, beta activity was negatively correlated with TTE (r = −.303, p < .01), overall AMQ scores (r = −.256, p < .05), and awareness (r = −.273, p < .01; Shown in Fig. 1.).

Table 2
Pearson correlations among TTE, AMQ, and PFC resting-state activity.

Variable	1.	2.	2 – 1.	2–2.	2–3.
1. TTE	–				
2. AMQ	.231*	–			
2 – 1. Attention	.296**	.843**	–		
2–2. Awareness	.207*	.831**	.583**	–	
2–3. Acceptance	.088	.825**	.560**	.481**	–
3. theta activity	–.195	–.166	–.114	–.141	–.157
4. alpha activity	–.186	–.141	–.049	–.169	–.125
5. beta activity	–.303**	–.256*	–.195	–.273**	–.170

Note. Abbreviation: TTE = Time to exhaustion; AMQ = Athlete Mindfulness Questionnaire. $N = 95$. *$p < 0.05$, **$p < 0.01$.

3.3. Test of mediating effect

The mediating role of PFC resting-state beta activity (M) in the relationship between AMQ (X) and TTE (Y) was examined using SPSS PROCESS Model 4. The mediating model are presented in Fig. 2-A, which shows that the total effect of overall AMQ scores on TTE was significant and positive (path *c*: $b = 56.91$, SE = 23.84, t = 2.39, $p = .019$), indicating that higher overall AMQ scores were associated with higher TTE when beta activity was not including in the model. However, after accounting for beta activity as a mediator, the direct effect of overall AMQ scores on TTE was no longer significant (path *c'*: $b = 41.07$, SE = 23.98, t = 1.71, $p = .090$), while indirect effect was significant (path *ab*: $b = 15.836$, $SE_{boot} = 8.361$, 95% CI [1.293, 35.070]). These finding support the mediating role of PFC resting-state activity between AMQ and TTE. Specifically, overall AMQ scores negatively predicted beta activity (path *a*: $b = -0.25$, SE = 0.09, $t = -2.59$, $p = .011$), and beta activity, in turn, negatively predicted TTE (path *b*: $b = -62.61$, SE = 24.57, $t = -2.55$, $p = .012$).

Given that awareness significantly associated with both beta activity and TTE, mediation analyses were conducted using awareness as the predictor (Fig. 2-B). The total effect of awareness on TTE was significant, (path *c*: $b = 44.62$, SE = 21.82, t = 2.05, $p = .044$), suggesting that awareness also served as a predictor of TTE when beta activity was not considered. Moreover, beta activity was found indirect effect between awareness and TTE as well (path *ab*: $b = 15.60$, $SE_{boot} = 8.49$, 95% CI [1.425, 34.291]), while the direct effect was not significant (path *c'*; $b = 29.02$, SE = 22.00, t = 1.32, $p = .190$). Similar to the overall AMQ, awareness negatively predicts beta activity (path *a*: $b = -0.24$, SE = 0.09, $t = -2.73$, $p = .008$) and beta activity negatively predict TTE (path *b*: $b = -64.59$, SE = 24.82, $t = -2.60$, $p = .011$).

4. Discussion

The present study examined association among mindfulness, endurance performance and PFC resting-state EEG activity in distance runners, and investigated the mediating role of PFC resting-state EEG activity in the association between mindfulness and endurance performance. The main findings indicated that higher overall AMQ scores were correlated with longer TTE and lower PFC resting-state beta activity. Among the three dimensions of AMQ, attention and awareness dimensions showed positive correlation with TTE, whereas only awareness was correlated with lower PFC resting-state beta activity. Mediation analysis further demonstrated a significant indirect effect of overall AMQ and awareness on TTE through PFC resting-state beta activity, indicating that runners with higher levels of mindfulness exhibited lower PFC resting-state beta activity, which in turn was associated with subsequent longer TTE. These findings partially support the initial hypothesis and suggest that PFC resting-state beta activity may be a neural pattern linking mindfulness to endurance performance.

4.1. Mindfulness as a predictor of endurance performance

Current study showed a significant positive correlation between mindfulness and endurance performance, which is consistent with previous research suggesting that athletes with higher levels of mindfulness tend to demonstrate better endurance performance. Sparks et al. (2021) reported that mindfulness positively related to rowing performance. With respect to endurance running, Thompson et al. (2011) found that higher mindfulness scores were positively correlated with one-mile running performance in distance runner. Compared with prior research, the present study employed an experimentally controlled endurance-running protocol that standardized performance assessment across participants, thereby minimizing potential confounding influences.

Further analyses of the three dimensions of AMQ revealed that attention and awareness were significantly correlated to longer TTE, suggesting athletes with higher levels of attention and awareness may contribute to notice bodily sensations, negative emotions, or irrelevant thoughts for the endurance tasks, and redirect their focus toward the task at hand without being distracted (Hill et al., 2021; Josefsson et al., 2019). Indeed, leading attention to the present moment during endurance running could optimize running economy and enhance perceived flow experience for endurance runner reach better performance (Josefsson et al., 2019). Additionally, Sparks et al. (2021) also suggested that awareness may mitigate anxiety-induced reinvestment during endurance running, thereby preventing athletes from excessively monitoring their movements under pressure. Interestingly, acceptance was not significantly correlated with endurance performance in the present study. This pattern may suggest that athletes rely more on attentional regulation and heightened awareness of bodily sensations, rather than acceptance-based strategies, to manage discomfort and other aversive internal experiences during endurance task. Consistent with this interpretation, Sparks et al. (2021) reported that acceptance was more strongly related to subjective performance indices than to objective performance outcomes. This distinction may also help explain the discrepancy with Thompson et al. (2011). Their study relied on self-reported endurance performance and found that description and acceptance were more strongly associated with

one-mile performance than attention and awareness, which may reflect perceived rather than objectively measured performance.

4.2. Association of frontal activation with mindfulness and endurance performance

Significant associations were observed only between PFC beta activity, mindfulness, and TTE. Beta activity has been associated with multiple negative psychological states, including stress-related responses (Ehrhardt et al., 2022) and anxiety-related modulation (Hein & Herrojo Ruiz, 2022), although evidence varies by task context and recording sites, which contrast with the relationship between mindfulness and these states (Röthlin et al., 2020). The current findings align with previous research demonstrating that higher levels of mindfulness are associated with reduced PFC beta activity (Izhar et al., 2022; Jung & Lee, 2021). In contrast, although the systematic review have suggested that alpha and theta activity may serve as neural markers of attention regulation and are generally positively associated with mindfulness (Lomas et al., 2015), such associations were not observed in the present study. One plausible explanation for these discrepancies is that participants in the present study had no prior mindfulness or meditation experience. Rodriguez-Larios et al. (2021) indicated that experienced meditators and novices exhibit distinct patterns of neural activity during meditation, suggesting that neural correlates of mindfulness differ with practice experience. As participants in the present study had no meditation experience, their resting-state EEG patterns may not reflect the neural signatures typically observed in trained individuals.

From a sport performance perspective, our findings indicate that greater PFC beta activity prior to performance was associated with shorter TTE, similar with evidence linking increased beta activity to suboptimal sport performance. For example, Pluta et al. (2018) found that higher PFC beta activity preceding a baseball batting task predicted poorer batting performance, whereas Rogala et al. (2020) reported that higher resting-state beta activity was associated with poorer subsequent shooting performance. The present study adds to the evidence suggesting a negative association between PFC resting-state beta activity and sport performance. Focusing specifically on endurance performance, Brownsberger et al. (2013) reported that mental fatigue impaired endurance cycling performance and was associated with elevated prefrontal beta activation. This association may be attributable to the fact that elevated prefrontal beta activity has been linked to negative psychological states such as anxiety (Hein & Herrojo Ruiz, 2022), which may impair sport performance (Sparks et al., 2021). Moreover, excessive resting-state PFC beta activity prior to performance may signal premature depletion of cognitive and metabolic resources, impairing attentional regulation in the endurance performance (Chandanathil et al., 2024; Grant & White, 2016; Nien et al., 2024). Overall, lower PFC resting-state beta activity may reflect a more adaptive preparatory state characterized by diminished maladaptive processing and efficient cognitive control, which in turn supports better endurance performance.

4.3. The indirect effect of mindfulness on endurance performance through PFC Beta activity

Current findings revealed that only PFC resting-state beta activity showed a significant indirect effect between AMQ and TTE, suggesting that lower pre-performance prefrontal beta activity mediates the association between mindfulness and endurance performance. A high level of mindfulness is associated with enhanced attentional control (Hill et al., 2021; Josefsson et al., 2019), improved emotional regulation (Treves et al., 2024), and greater tolerance to discomfort (Boat & Taylor, 2017). These benefits of mindfulness may reduce the unnecessary engagement of self-regulation processes (e.g., cognitive control and emotional suppression) elicited by negative psychological states prior to performance (Boat & Taylor, 2017; Grant & White, 2016).

From the perspective of strength model of self-control, self-regulation relies on a finite pool of cognitive resources that can be depleted through sustained mental effort (Baumeister et al., 2007). Elevated beta activity has been interpreted as an index of increased cortical effort and neural resource expenditure, particularly under conditions of high cognitive demand (Proost et al., 2024). Accordingly, higher mindfulness may enable athletes to sustain focus on goal-relevant cues and attenuate internal distractions more efficiently, thereby optimizing preparatory states for endurance performance (Rogowska & Tataruch, 2024). In addition, the present findings suggest that athletes with higher awareness may detect and avoid negative cognitive engagement (e.g., worry-driven monitoring) at an earlier stage. Collectively, mindfulness may preserve self-control resources by reducing excessive pre-performance cognitive effort, with PFC beta activity representing a potential neural correlate linking mindfulness to endurance performance.

4.4. Limitations and future directions

The present study sought to preliminarily clarify, from a neurocognitive perspective, the associations between mindfulness and endurance performance. However, several limitations should be acknowledged and addressed in future research. First, this study adopted a cross-sectional design, which allows examination of associations among variables but does not permit causal inference. Future studies are encouraged to employ experimental designs and pre–post comparisons to test whether mindfulness interventions directly reduce beta activity and enhance endurance performance, thereby providing stronger validation for the proposed neural mechanism model. Second, negative psychological states such as anxiety and mental fatigue were not directly measured in the present study, which limits the interpretation to the association between beta activity and negative psychological states. Future research could incorporate self-report and physiological measurement of anxiety or mental fatigue to strengthen the empirical basis for beta activity as an index of negative psychological processes. Moreover, experimental manipulations or interventions inducing mental fatigue could further test whether mindfulness regulate beta activity and protects endurance performance, helping to build a more comprehensive explanatory model. Lastly, the EEG analysis in this study focused solely on the activity strength of a single brain region, which does not capture the functional connectivity or coherence between cortical areas. Future studies may incorporate coherence or functional connectivity analyses to examine how mindfulness influences neural interactions across brain regions during endurance performance.

5. Conclusion

The present study found that higher mindfulness was associated with lower PFC resting-state beta activity prior to the endurance running, which in turn was associated with longer time to exhaustion. These findings not only align with prior behavioral evidence linking mindfulness to endurance performance, but also provide preliminary support for PFC resting-state beta activity as a potential neural correlate of the association between mindfulness and endurance performance.

6. Perspectives

Higher mindfulness may indicate a more adaptive preparatory state, characterized by lower cognitive load and reduced maladaptive engagement. From a neurophysiological perspective, this state may be reflected in lower resting-state beta activity in the prefrontal cortex, suggesting a more efficient and less overactivated preparatory state, which in turn is associated with better endurance performance. Accordingly, using AMQ assessments prior to competition, coaches and athletes can identify suboptimal mental states and implement mindfulness-based strategies to regulate cognitive and emotional processes and to buffer the potential negative impact of maladaptive psychological states on performance. Overall, these findings propose a potential mindfulness-based pre-performance readiness framework for endurance performance that can be applied by coaches and athletes to monitor and optimize performance by integrating psychological and neurophysiological evidence.

Declarations

Author Contribution

Yun-Rui Yang: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. Jui-Ti Nien: Conceptualization, Methodology, Investigation, Formal analysis, Writing – review and editing. Dong-Tai Chen: Investigation, Formal analysis, Writing – review and editing. Chueh-Yin Chen: Investigation, Writing – review and editing. Liye Zou: Writing – review and editing. Yu-Kai Chang: Conceptualization, Methodology, Supervision, Writing – review and editing.

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Data Availability

Data supporting the findings of this study may be available from the corresponding author upon reasonable request, subject to ethical approval and institutional restrictions.

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Figures

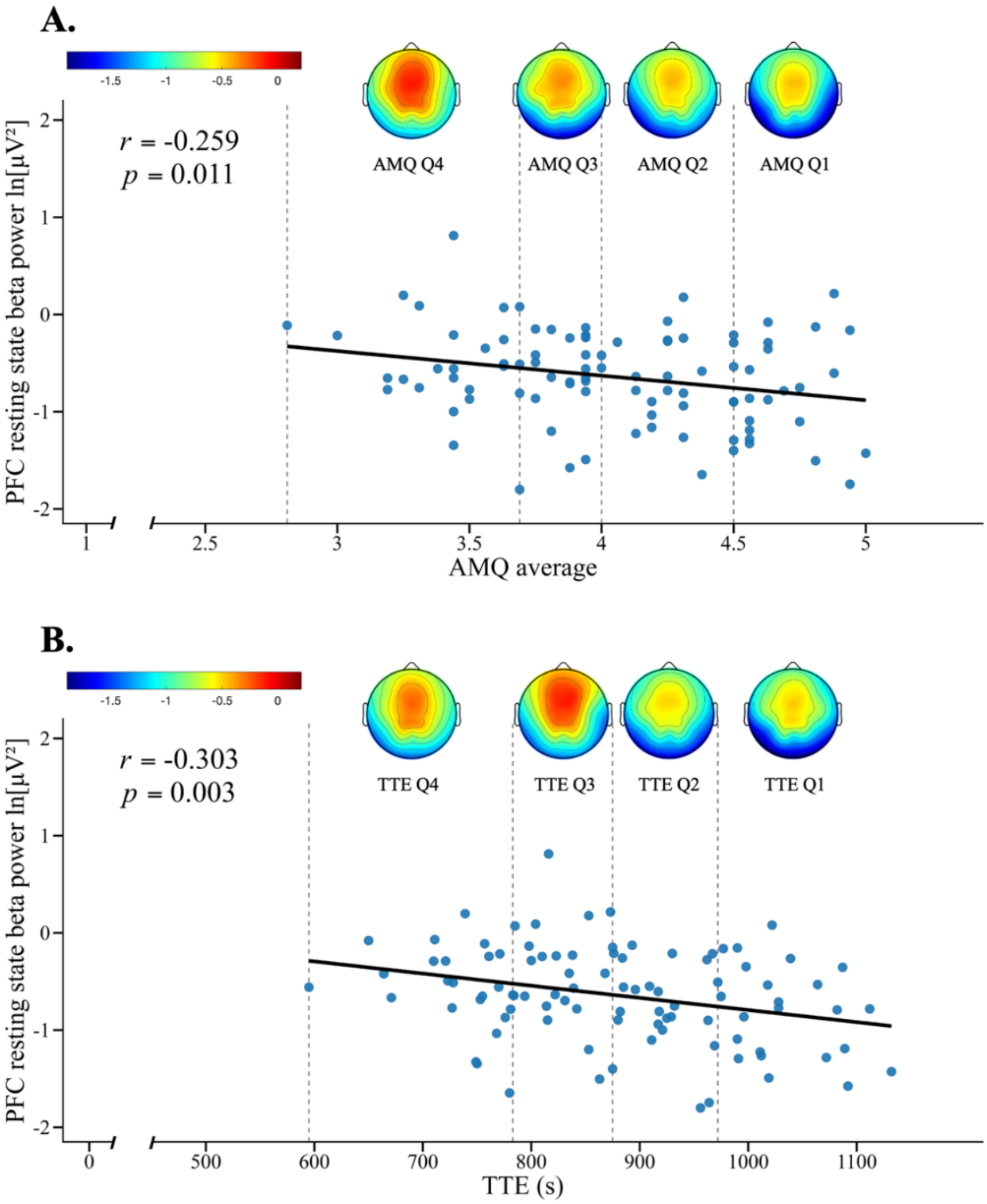


Figure 1

Associations of AMQ and TTE with PFC resting-state beta power

Note. Abbreviation: TTE = Time to exhaustion; AMQ = Athlete Mindfulness Questionnaire. Panel A shows the scatterplot of AMQ (average score) versus PFC resting-state beta power, represented as natural log transformed power [ln (μV²)]. Panel B shows the scatterplot of TTE (s) versus PFC resting state beta

power [ln (μV²)]. Scalp topographies depict the mean beta power for each quartile group of AMQ (A.) and TTE (B.). Quartiles were formed by ranking participants on AMQ (A.) or TTE (B.) and then dividing them into four equal sized groups (approximately 25% of the sample per group).

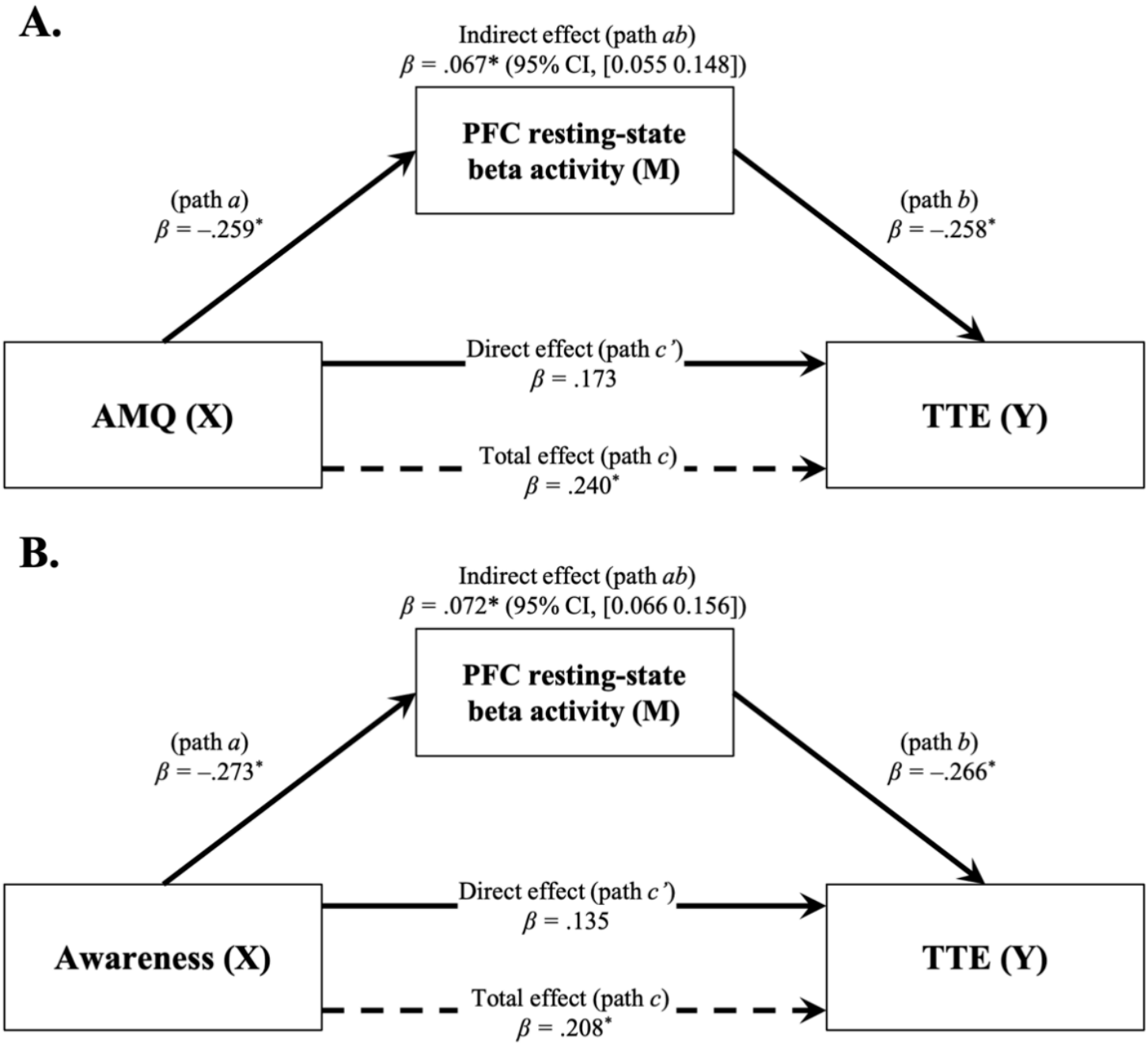


Figure 2

Standardized mediation models of PFC resting-state beta activity in the association between mindfulness and endurance performance.

Note. Abbreviation: TTE = Time to exhaustion; AMQ = Athlete Mindfulness Questionnaire. Panel A. shows the indirect effect of overall AMQ scores on time to exhaustion through PFC resting-state beta

activity. Panel B. shows the indirect effect of awareness on time to exhaustion through PFC resting-state beta activity. Values are standardized coefficients. Bootstrap 95% confidence intervals are presented for the indirect effects. *$p < .05$.