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Enhancing shooting performance and cognitive engagement in virtual reality environments through brief meditation training

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Mindfulness meditation training has been associated with improved cognitive and sport performance, but the mechanisms linking mindfulness, cognitive engagement, and performance remain unclear, especially in simultaneous assessments during sports tasks. This study explored whether brief mindfulness meditation (BMM) training impacts shooting performance and cognitive engagement. We hypothesized that: (1) the meditation group would show improved shooting performance compared to the control group, and (2) daily 15-min mindfulness meditation would enhance cognitive engagement, reflected by brain activity. Sixty participants were randomly assigned to either an 18-day mindfulness meditation group or a control group. A virtual reality (VR) shooting task assessed performance before and after the intervention, while portable EEG devices recorded brain activity. The meditation group improved shooting scores by 6.56 points ($p = 0.036$) and showed a higher Beta/(Alpha + Theta) ratio—a marker of cognitive engagement reflecting greater focus and alertness versus relaxation—in left frontal regions (AF3, AF7, Fp1), but not right regions (AF4, AF8, Fp2). These findings suggest that BMM can improve both motor precision and mental focus, making it a valuable tool for athletes and professionals in high-precision fields such as surgery and aviation. Integrating short BMM sessions into training routines may help optimize focus and performance.

Keywords Mindfulness meditation, Cognitive engagement, Shooting performance, Virtual reality

Psychological interventions are increasingly recognized for their role in optimizing athletic performance[1,2]. Among these, mindfulness meditation has emerged over the past decade as a valuable practice for enhancing sport-related mental abilities[3]. Defined as a mental discipline involving focused attention, present-moment awareness, and a nonjudgmental stance[4,5], mindfulness training strengthens athletes' ability to regulate attention and maintain focus on task-relevant cues[6]. This is particularly crucial in precision sports like shooting, where high cognitive engagement—sustained allocation of mental resources to relevant tasks[7–9]—is essential for maintaining accuracy under pressure[10–13].

Recent studies have further revealed the positive impact of mindfulness training on the cognitive functions of shooting athletes. According to a study by Bu et al.[14] elite shooters demonstrated improved attention following a mindfulness training program. Additionally, researchers found that mindfulness training for 5–8 weeks enhanced the orienting and conflict-control networks of elite shooters and archers[15]. Wu et al.[6] discovered that a 4-week mindfulness-based intervention (MBI) improved shooting performance, multiple cognitive functions, and mindfulness levels in archers. These findings highlight the role of mindfulness in enhancing not only cognitive engagement but also sport-specific performance, such as accuracy and consistency in shooting. However, most previous studies have focused on highly trained or elite athletes, leaving a significant gap in understanding how mindfulness affects novices. Elite athletes typically have well-developed attentional control and cognitive engagement strategies, which may interact with mindfulness training in ways that do not directly translate to beginners. Novice athletes, on the other hand, often struggle with maintaining focus, filtering distractions, and executing precise motor actions under pressure. Investigating whether mindfulness can provide similar cognitive and performance benefits for beginners is crucial, as they may require different training approaches

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compared to elite athletes. Addressing these gaps is essential to provide practical training strategies that can benefit athletes at all skill levels.

The theoretical framework underlying these findings posits that mindfulness training enhances cognitive engagement by modulating neural mechanisms associated with attention and self-regulation, leading to better task-specific performance. Research in neuroscience provides further support for this framework. For example, mindfulness meditation modifies cerebral blood flow and white matter connectivity in key regions like the anterior cingulate cortex (ACC) and prefrontal cortex (PFC)[16], enhancing attentional control and reducing distraction—vital for high-pressure tasks like shooting. Electroencephalography (EEG) studies further reveal increased β wave power (tied to focused attention) and decreased δ wave power (linked to mind-wandering)[17]. Aly et al. showed that a single 20-min session improved cognitive task accuracy and reduced P3 amplitude in event-related potentials (ERPs), reflecting more efficient attention allocation[18] Such findings suggest that mindfulness practice not only enhances attention regulation but also optimizes cognitive processing, which is particularly valuable in shooting sports, where athletes must rapidly process key visual and motor information to achieve precision. Although studies confirm benefits like enhanced elite shooting performance and reduced tension[19], few explore how mindfulness meditation connects cognition and shooting performance, especially during integrated tasks rather than separate assessments. Moreover, it was also challenging to apply the findings to inexperienced athletes because earlier studies tended to concentrate on elite athletes. Bridging this gap is key to unlocking real-time insights and practical training strategies for athletes across skill levels.

According to Kaufman et al.[20] in order for mindfulness training to have an influence on athletes' personal development, a period of practice longer than 4 weeks is recommended. However, considering the associated time commitment, teacher shortage, and high cost, it is difficult for many athletes to maintain mindfulness training for a long period of time. As a result, it is of great practical significance and social value to develop a time-saving, economical, simple, and effective meditation training method and explore its possible influence on attention function. Recently, brief mindfulness meditation (BMM) training has attracted increasing attention. BMM is an effective, convenient, safe, and standardized meditation approach that can improve practitioners' mood and emotional processing. Compared with structured meditation programs such as Kabat-Zinn's traditional 8-week mindfulness-based stress reduction therapy, BMM is not restricted by time or place, has the advantages of convenience and low cost, and has a good application prospect[21].

Building on this theoretical framework, the present study aimed to investigate the effects of BMM on both cognitive engagement and shooting performance. We hypothesized that: (1) participants in the mindfulness meditation group would show significant improvements in shooting performance compared to the control group; and (2) 15-min daily mindfulness meditation training would enhance cognitive engagement during shooting tasks, as reflected by EEG measures of brain activity. To test these hypotheses, we integrated virtual reality (VR) technology, human–computer interaction, and BMM techniques to create a VR-simulated shooting environment. Participants' brain activity was recorded using portable EEG devices during shooting tasks before and after an 18-day intervention.

Method

Participants

Sixty participants were recruited from a university in Shanghai. The participants were included in the study based on the following criteria: (a) no prior experiences of mindfulness-related training (e.g., meditation, yoga, or Tai Chi); (b) no prior experiences of shooting-related training; (c) no history of psychiatric or neurological disorders; (d) not taking medicines affecting the central nervous system or brain; and (e) normal or corrected-to-normal vision and no color blindness. Novices were chosen because previous research has primarily focused on elite athletes, leaving a gap in understanding how mindfulness affects beginners. Unlike elite athletes, who have well-developed attentional control, novices often struggle with focus, distraction filtering, and precise motor execution under pressure. Studying novices allows us to assess mindfulness's foundational effects on cognitive engagement and performance without confounds from prior experience.

The sample size was calculated using G*Power 3.1 software. The specific parameters were set as follows: F-test, ANCOVA: Fixed effects, omnibus, one-way[22]. The effect size was based on the average effect size reported in similar research on brief mindfulness exercises[21,23]. A significance level of 0.05 and a statistical power of 0.80 were applied, yielding a required total sample size of no less than 52 participants.

Participants were randomly assigned via a computer-generated process to the BMM group ($n = 30$; 14 females; 22 with college or higher education) or the control group ($n = 30$; 11 females; 29 with college or higher education). Allocation concealment was ensured by employing a central allocation system, where the sequence was implemented by an independent researcher who was not involved in the recruitment or assessment of participants. Participants completed a questionnaire that collected information on their age, vision, education background, familiarity with virtual reality, and familiarity with shooting games. This information was used to assess the baseline characteristics of both groups to ensure that potential confounding variables were balanced across the two groups.

All participants successfully completed the entire program, provided their signed informed consent prior to participation, and received financial compensation for their time. Informed consent for the publication of any identifying information or images was obtained from either the participants themselves or their legal guardians. All study procedures received approval from the Naval Medical University Medical Ethics Committee and adhered to the principles of the Declaration of Helsinki. Participants were provided with comprehensive information about the nature of the study, including the procedures, potential risks, and confidentiality of EEG data. Participants were informed that their participation was voluntary, and they could withdraw at any time without penalty.

Procedures

The experiment was conducted in a quiet room. A total of 60 participants completed a demographic questionnaire and were then randomly assigned to either the BMM group or the control group. Prior to the intervention, all participants completed a virtual reality shooting task. The shooting task required participants to hold a simulated rifle and wear a virtual reality headset with integrated EEG devices, immersing them in a virtual reality environment. Participants initially underwent 10 shooting practice sessions to adapt to the virtual reality setting. Subsequently, they completed 5 shooting tasks while their behavioral performance and EEG data were simultaneously recorded.

During the intervention phase, participants in the BMM group engaged in daily 15-min mindfulness meditation exercises. At the same time, the control group received no intervention, were asked to wait without engaging in any activities, and were not allowed to use their phones or any other smart devices during this period. The intervention process lasted for 18 days.

After the intervention, all participants completed the virtual reality shooting task once again, with the same requirements as the pretest. The participant flow throughout the study is illustrated in Fig. 1, which details the stages of enrollment, randomization, intervention, and analysis, following CONSORT recommendations.

Measurements

Shooting task

The game engine Unity3D was used to develop a VR shooting task integrating 6-channel EEG. The VR device used is the HTC Vive™jointly developed by HTC International Electronics and Villefort (Fig. 2A). It provides users an immersive experience of a three-dimensional virtual space and achieves experimental purposes with a handheld remote controller. The EEG device is produced by Looxid®, which can receive 6-channel EEG data.

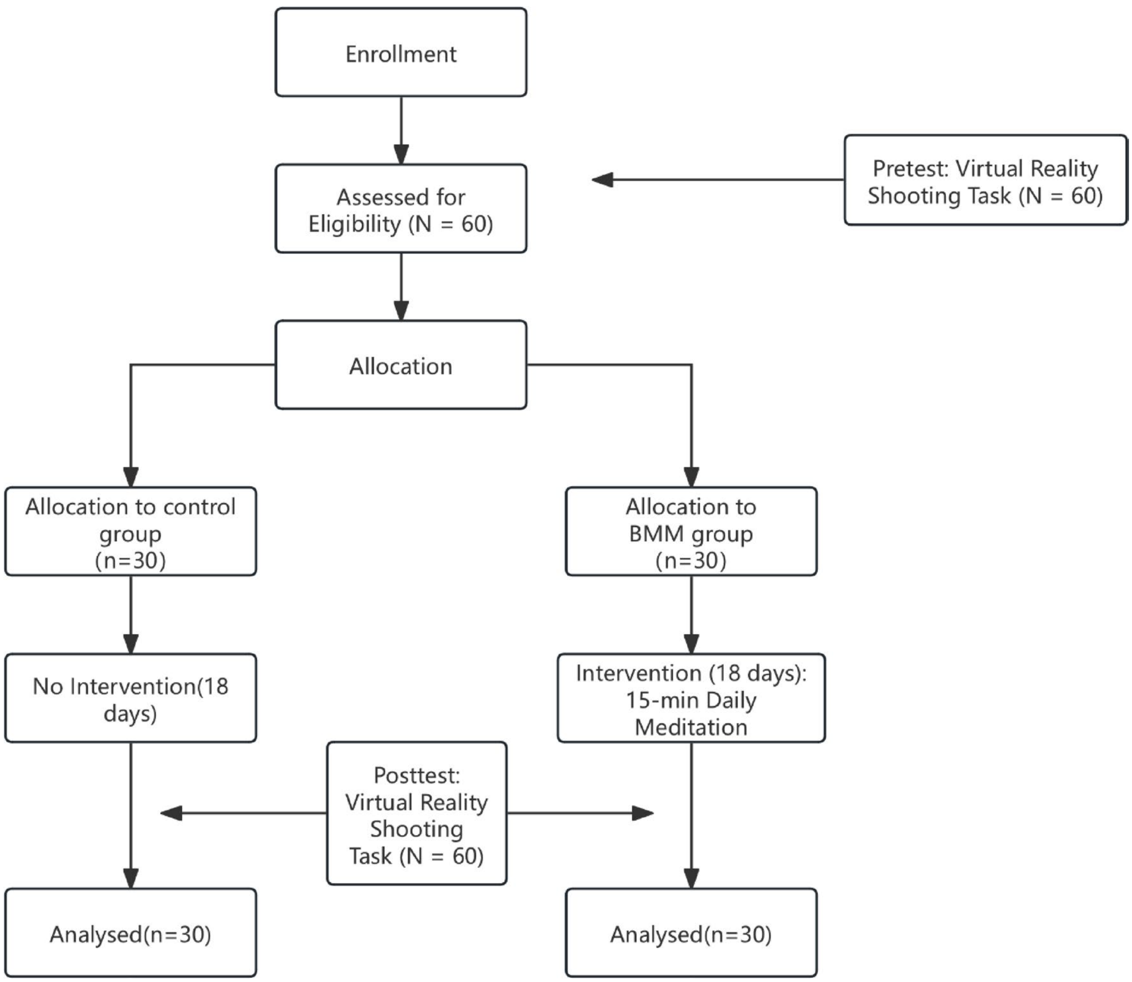

Fig. 1. Participant flow diagram following CONSORT guidelines. This diagram illustrates the study design, including participant enrollment, allocation into groups, intervention, and posttest analysis. Participants were randomly assigned to either the control group (n = 30), which did not receive any intervention, or the intervention group (n = 30), which engaged in daily 15-min mindfulness meditation for 18 days. Pretest and posttest virtual reality shooting tasks were conducted to measure performance outcomes.

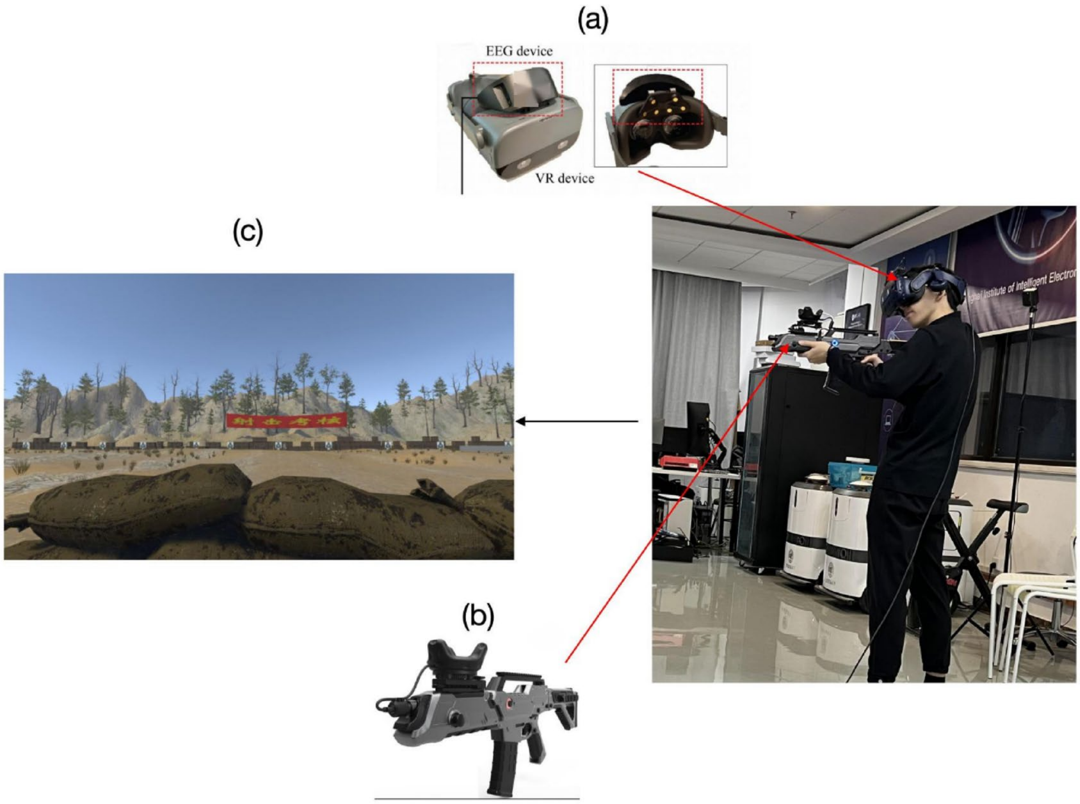

Fig. 2. Experimental setup for virtual reality shooting task with EEG monitoring. The figure illustrates the key components of the VR shooting task. (**A**) Participants wore a VR headset integrated with an EEG device to record brain activity during the task. (**B**) Participants held a simulated rifle equipped with sensors to interact with the virtual environment. (**C**) The virtual environment simulates a shooting range, where participants performed a shooting task after an initial practice phase to familiarize themselves with the setup. The arrows indicate the interaction between the participant, the VR equipment, and the virtual environment.

The HTC Vive™and VR controllers are connected to the computer, enabling users to interact with the virtual environment.

The VR environment was designed to closely replicate a real-world outdoor shooting range, enhancing ecological validity (Fig. 2C). The virtual range was modeled after an outdoor shooting range in Shanghai, incorporating realistic environmental features such as terrain, vegetation, and weather conditions to create an immersive experience. The scene was set in an outdoor environment on a clear day, with a grassy field in the foreground and distant mountains in the background, simulating the visual context of an actual shooting range. Participants adopted a standing shooting posture and aimed at a virtual target positioned 50 m away, in accordance with International Shooting Sport Federation (ISSF) regulations[24]. The target featured 10 concentric rings, with scores ranging from 10 for a center hit to 0 for a complete miss. The VR system ensured consistent environmental conditions, providing a standardized shooting experience for all participants. To further enhance realism, participants used a VR-compatible rifle (Fig. 2B) that simulated the weight, grip, and aiming mechanics of a real firearm. An electronic scoring system automatically recorded shot placements, providing an objective measure of shooting performance based on accuracy and precision.

EEG data

The EEG data was captured using Looxid Labs' innovative VR-mounted EEG recording device. This device features a wearable unit containing six dry electrodes, strategically positioned to target the prefrontal area (AF3, AF4, AF7, AF8, Fp1, and Fp2). The recorded EEG data, comprising 500 data points per second, underwent processing through Looxid Link Core. This advanced processing module analyzes the data to provide valuable insights into concentration, relaxation, and the balance between the left and right hemispheres of the brain. Furthermore, it provides real-time updates of alpha, beta, gamma, delta, theta, and other relevant frequency band values, with a refresh rate of 100 ms.

In this experiment, we used the Beta/(Alpha + Theta) ratio as an indicator of cognitive engagement, which reflects how actively the brain is involved in a task. Previous research has shown that this ratio is a reliable measure of cognitive engagement, as it captures the balance between different brainwave activities associated with attentional control and mental effort[25–27]. Beta waves are linked to active thinking, problem-solving, and sustained attention, while Alpha waves are associated with relaxation, and Theta waves are related to drowsiness and reduced cognitive control. A higher Beta/(Alpha + Theta) ratio indicates increased focus and task involvement, whereas a lower ratio suggests a more relaxed or distracted state. Therefore, we extracted the power in the Alpha, Beta, and Theta frequency bands from − 1000 to 0 ms relative to the moment of shooting, and calculated the Beta/(Alpha + Theta) ratio as an index of cognitive engagement. Given that shooting performance is closely related to cognitive processes such as attention, which are primarily associated with the frontal brain regions, we selected data from six frontal channels (AF3, AF4, AF7, AF8, Fp1, and Fp2).

Intervention

The interventions were single-blind in design, and participants did not know the purpose of the experiment. The BMM program used in this study was designed by a facilitator with more than ten years of experience and training in meditation. This BMM (JW2016) was produced based on the core concepts of mindfulness and Buddhist Vipassana breath meditation[28], combined with knowledge gained from our practical experience and scientific reports on meditation. Previous research has proved that BMM (JW2016) is an effective, convenient, safe, and standardized meditation approach[21]. During BMM training, participants followed audio instructions to practice their meditation skills. The audio instructions comprised 1 min of guided preparation and 15 min of mindfulness meditation training. Participants were instructed to close their eyes, relax, and focus on the flow of their breath. They were told to notice and acknowledge the thoughts that arise passively and to let them go by bringing their attention back to their breath.

Statistical analyses

SPSS 26.0 was used to perform the statistical analysis. The means and standard deviations of the demographic data and questionnaire outcomes were calculated using descriptive statistics. One-way analyse of covariance (ANCOVA) is recommended for use in experimental designs to prevent bias from treatment effects[29]. Before conducting ANCOVA, the necessary assumptions were verified: Levene's test confirmed equal variances across groups, Q–Q plots and the Shapiro–Wilk test indicated normal distribution of residuals within each group, the relationship between the covariate (preintervention scores) and the dependent variable was linear for all groups, and regression lines for the covariate and dependent variable were parallel across groups, as confirmed by statistical tests and graphical analysis. Following these checks, separate ANCOVAs were conducted to compare postintervention cognitive engagement and shooting performance, controlling for preintervention scores. The effect size was calculated using a partial η^2 for the variance between groups when a significant effect was observed. A p value of less than 0.05 was statistically significant.

Results

Demographics characteristics and baseline comparison results

The important demographics of the participants are presented in Table 1. The BMM group and control group demonstrated no significant difference in age, vision, education background, familiarity with virtual reality and familiarity with shooting games (all $p > 0.05$), indicating that the groups were demographically comparable.

To ensure the comparability of the two groups before the intervention, independent samples t-tests were also conducted to examine baseline differences in cognitive engagement (Beta/(Alpha + Theta) ratio) and shooting

		BMM Group ($n = 30$)		Control Group ($n = 30$)				
		Mean	*SD*	Mean	*SD*	*t*	*p*	Cohen's *d*
Demographic characteristics	Age	23.97	2.04	23.43	1.48	− 1.16	0.252	0.30
	Gender	1.47	0.51	1.37	0.49	− 0.78	0.441	0.20
	Left eye vision	4.85	0.30	4.69	0.79	− 1.00	0.324	0.26
	Right eye vision	4.85	0.30	4.72	0.78	− 0.88	0.384	0.23
	Education background	2.20	0.55	2.13	0.43	− 0.52	0.605	0.13
	Familiarity with virtual reality	2.27	1.41	1.93	0.98	− 1.06	0.293	0.27
	Familiarity with shooting games	3.17	1.39	3.23	1.17	0.20	0.841	0.05
Cognitive engagement baseline	AF3	0.52	0.03	0.51	0.03	0.11	0.906	0.03
	AF4	0.51	0.03	0.51	0.03	0.27	0.787	0.07
	AF7	0.51	0.03	0.51	0.03	− 0.01	0.990	0.00
	AF8	0.51	0.02	0.50	0.02	− 0.63	0.531	0.17
	Fp1	0.52	0.02	0.51	0.02	− 0.40	0.689	0.11
	Fp2	0.51	0.02	0.51	0.03	0.34	0.735	0.09
Shooting performance baseline	Shooting Performance	24.00	12.92	23.97	15.46	− 0.01	0.993	0.00

Table 1. Demographic characteristics and baseline comparison of cognitive engagement and shooting performance between the BMM and control groups. *BMM*, Brief Mindfulness Meditation.

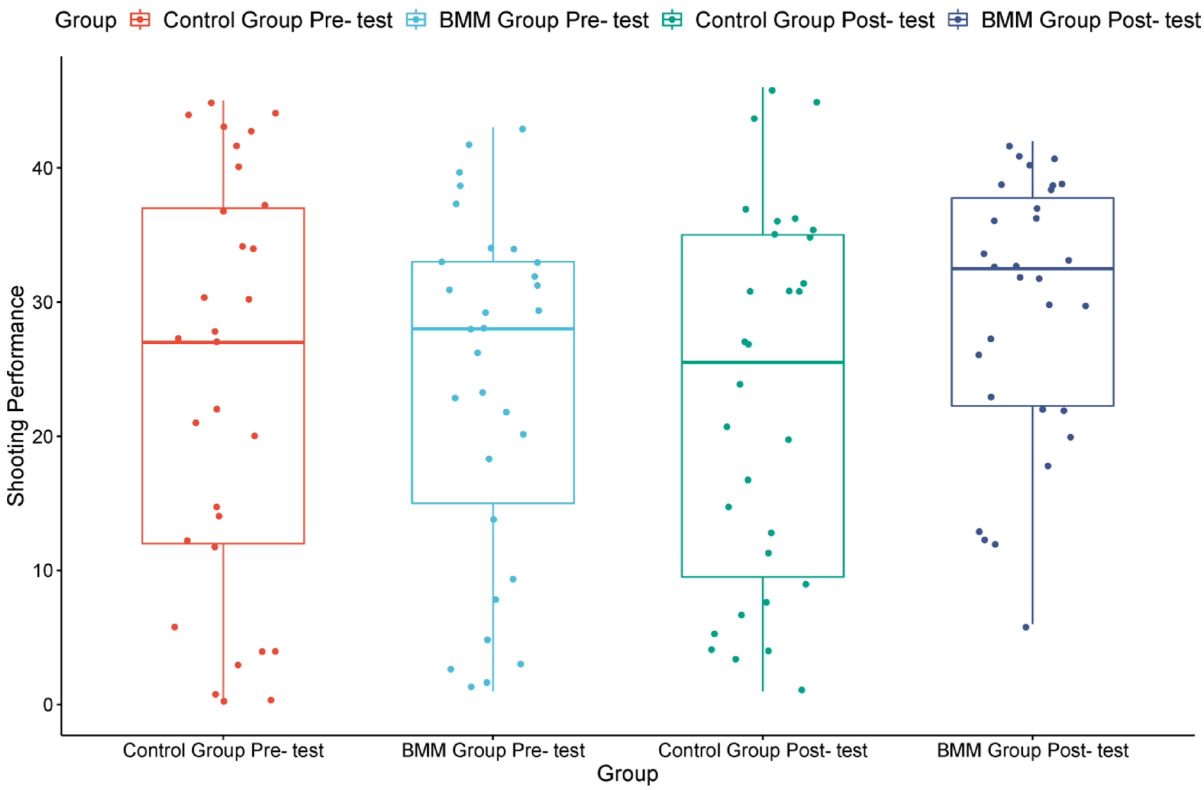

Fig. 3. Changes in shooting performance before and after the intervention for both groups. Boxplots illustrating shooting performance scores for the BMM group and control group at pre-test and post-test. Individual data points represent participants' scores.

	BMM Group (n = 30)			Control Group (n = 30)		
	Pretest ($M \pm SD$)	Posttest ($M \pm SD$)	Adjusted posttest ($M \pm SE$)	Pretest ($M \pm SD$)	Posttest ($M \pm SD$)	Adjusted posttest ($M \pm SE$)
Shooting performance	24.00 ± 12.92	29.53 ± 10.03	29.53 ± 2.16	23.97 ± 15.46	22.97 ± 13.99	22.97 ± 2.16

Table 2. Descriptive statistics of pretest, posttest, and ANCOVN adjusted posttest shooting performance. *BMM*, Brief Mindfulness Meditation.

performance. As shown in Table 1, there were no significant differences between the groups in any of these baseline measures (all $p > 0.05$).

These findings indicate that both groups were comparable in terms of demographic characteristics and baseline cognitive engagement and shooting performance, ensuring that any post-intervention differences are unlikely to be attributed to pre-existing group differences.

Shooting performance

ANCOVA demonstrated a statistically significant enhancement in shooting performance for the BMM group relative to the control group following an 18-day intervention ($F = 4.50$, $p = 0.038$, $\eta^2 = 0.07$, 95% CI 0.003–0.186) (Fig. 3). Post hoc analyses with Bonferroni adjustment showed that after the intervention, the BMM group scored 6.56 points higher than the Control group (95% CI 0.438–12.685, $p = 0.036$)(Table 2). The effect size ($\eta^2 = 0.07$) suggests a moderate impact, while the CI (0.438 to 12.685) indicates the improvement is reliably above zero, reinforcing BMM's potential as a training tool for novices. Given that a 6.56-point increase could be substantial in competitive shooting, these findings highlight the potential benefits of BMM training for performance enhancement.

Cognitive engagement

The ANCOVA results revealed significant differences in cognitive engagement between the BMM and control groups in three electrode sites located in the left frontal region: AF3, AF7, and Fp1. Specifically, the BMM group showed significantly higher cognitive engagement compared to the Control group at AF3 $F = 4.35$, $p = 0.042$, $\eta^2 = 0.08$, 95% CI 0.004–0.201), AF7 ($F = 4.27$, $p = 0.044$, $\eta^2 = 0.07$, 95% CI 0.003–0.186), and Fp1 ($F = 4.40$, $p = 0.041$, $\eta^2 = 0.08$, 95% CI 0.004–0.202). Post hoc analyses with Bonferroni adjustment further indicated that after the intervention, the BMM group scored 0.019 points higher than the Control group at AF3 (95% CI

	BMM group			Control group		
	Pretest ($M \pm SD$)	Posttest ($M \pm SD$)	Adjusted posttest ($M \pm SE$)	Pretest ($M \pm SD$)	Posttest ($M \pm SD$)	Adjusted posttest ($M \pm SE$)
AF3	0.52 ± 0.03	0.54 ± 0.04	0.54 ± 0.01	0.51 ± 0.03	0.52 ± 0.03	0.52 ± 0.01
AF4	0.51 ± 0.03	0.52 ± 0.03	0.52 ± 0.01	0.51 ± 0.03	0.51 ± 0.03	0.51 ± 0.01
AF7	0.51 ± 0.03	0.54 ± 0.04	0.54 ± 0.01	0.51 ± 0.03	0.52 ± 0.03	0.52 ± 0.01
AF8	0.51 ± 0.02	0.52 ± 0.03	0.52 ± 0.01	0.50 ± 0.02	0.51 ± 0.03	0.51 ± 0.01
Fp1	0.52 ± 0.02	0.54 ± 0.04	0.54 ± 0.01	0.51 ± 0.02	0.52 ± 0.03	0.52 ± 0.01
Fp2	0.51 ± 0.02	0.52 ± 0.03	0.52 ± 0.01	0.51 ± 0.03	0.52 ± 0.03	0.52 ± 0.01

Table 3. Descriptive statistics of pretest, posttest, and ANCOVN adjusted posttest cognitive engagement. *BMM*, Brief Mindfulness Meditation.

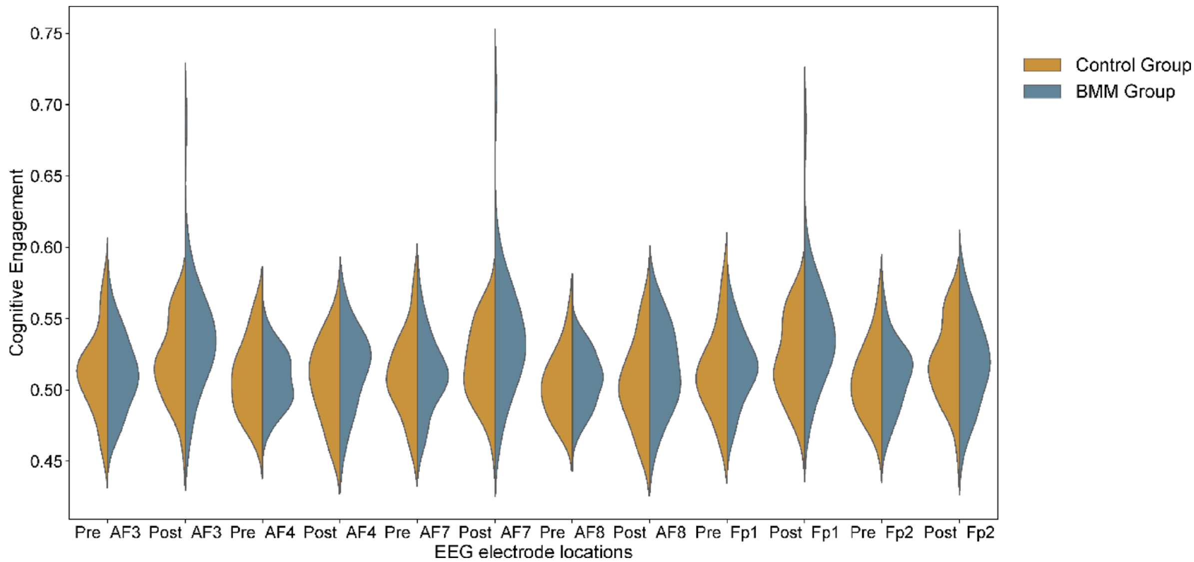

Fig. 4. Changes in cognitive engagement across EEG electrode locations before and after the intervention. Violin plots depicting the distribution of cognitive engagement (Beta/(Alpha + Theta) ratio) for the BMM group and control group at different EEG electrode locations (AF3, AF4, AF7, AF8, Fp1, and Fp2) before (Pre) and after (Post) the intervention.

0.001–0.038, $p = 0.042$), 0.020 points higher at AF7 (95% CI 0.000–0.040, $p = 0.045$), and 0.019 points higher at Fp1 (95% CI 0.001–0.038, $p = 0.042$). These findings suggest that BMM intervention may enhance cognitive engagement in the left frontal cortex, a region often associated with attention and executive function.

However, no significant differences were found between the BMM and Control groups in the right frontal region at AF4 ($F = 2.47$, $p = 0.122$, $\eta^2 = 0.04$, 95% CI 0.000–0.128), AF8 ($F = 1.51$, $p = 0.218$, $\eta^2 = 0.03$, 95% CI 0.000—0.098), and Fp2 ($F = 0.00$, $p = 0.947$, $\eta^2 = 0.00$, 95% CI 0.000–0.000). The effect sizes for these sites were small ($\eta^2 \leq 0.04$), indicating that the intervention had minimal or no measurable impact on cognitive engagement in these areas (Table 3).

Overall, these results highlight a lateralized effect of the BMM intervention, with significant improvements in cognitive engagement observed in the left frontal cortex, whereas the right frontal cortex showed no significant changes. This lateralization aligns with previous findings suggesting that the left frontal lobe plays a dominant role in cognitive control and attentional processes. The observed effect sizes ($\eta^2 = 0.07$–0.08) indicate a moderate practical impact, meaning that while the differences are statistically significant, they are also meaningful in the context of cognitive training interventions (Fig. 4).

Discussion

This study demonstrate that a brief 18-day meditation training can effectively enhance shooting performance in a virtual reality environment. This improvement in performance is further supported by neurophysiological data, showing a higher Beta/(Alpha + Theta) ratio during the shooting task in the meditation group compared to the control group, indicating a greater level of cognitive engagement.

Brief mindfulness meditation improve shooting performance

We observed that BMM training significantly enhanced shooting performance in male novice athletes, with participants in the BMM group achieving higher scores than those in the control group after 18 days. This improvement aligns with previous research showing that mindfulness training enhances precision in tasks requiring focus and accuracy, such as shooting and dart throwing[12,30,31]. Importantly, while most studies have focused on elite athletes, our findings suggest that mindfulness benefits extend to novice participants, helping them develop fundamental skills.

Mindfulness encompasses various techniques, including body scan meditation, loving-kindness meditation (LKM), mindfulness-based stress reduction (MBSR), and mindfulness-based cognitive therapy (MBCT). While longer interventions (e.g., MBSR) have been found to improve performance in precision-based sports, they often require significant time commitments, limiting their accessibility[32–35]. In contrast, BMM, as a brief and efficient intervention, significantly improved shooting performance within just 18 days, suggesting that short-term mindfulness practice can rapidly enhance attention and minimize distractions in high-precision tasks. This makes BMM a practical alternative to longer programs, particularly for novice athletes or individuals with limited training time.

Furthermore, while our study focused on shooting, the benefits of BMM may extend to other precision-demanding fields such as esports, military training, and surgery. In professional gaming, sustained attention and rapid decision-making are critical, and BMM may help players maintain focus during high-pressure situations. Similarly, military personnel and law enforcement officers, who rely on precision shooting and quick responses, could benefit from incorporating short mindfulness sessions into training to improve cognitive control and accuracy.

Mindfulness meditation enhances left brain cognitive engagements during shooting

Our study found that BMM significantly increased the Beta/(Alpha + Theta) ratio in the left frontal lobe during shooting tasks, with the meditation group showing a notably higher ratio than the control group. Since Beta waves are associated with active thinking and attentional control, while Alpha and Theta waves reflect more relaxed and less focused states, a higher Beta/(Alpha + Theta) ratio suggests greater cognitive engagement. This implies that BMM may help individuals maintain focus and process task-relevant information more efficiently, which is crucial for precision-demanding activities.

Further analysis showed that this effect was most pronounced in AF3, AF7, and Fp1 (left frontal lobe), whereas no significant changes were observed in AF4, AF8, and Fp2 (right frontal lobe). This suggests that BMM primarily enhances cognitive processes related to goal-directed attention and decision-making, which are predominantly left-lateralized, rather than emotional regulation, which is more associated with the right frontal lobe. However, it is possible that tasks requiring greater emotional control, such as public speaking or stress-intensive decision-making, might elicit stronger effects in the right frontal region.

These findings have important practical implications beyond shooting sports. In competitive gaming (esports), where sustained attention, rapid decision-making, and fine motor control are critical, BMM could help players maintain cognitive sharpness and reduce distractions during high-pressure matches. Similarly, in military and law enforcement settings, where precision shooting and quick, high-stakes decisions are required, BMM could serve as a practical cognitive training tool. The ability to stay highly focused under pressure is essential in these fields, and brief mindfulness exercises could be integrated into training programs to enhance performance without requiring significant time commitments.

Compared to long-term mindfulness programs like 8-week MBSR, which have been shown to induce structural changes in the brain[16,36], our 18-day intervention primarily led to functional improvements. While these short-term gains in cognitive engagement and shooting performance are promising, it remains unclear whether such a brief intervention can produce long-term neural adaptations. Additionally, as participants in the BMM group may have expected performance improvements, placebo effects cannot be entirely ruled out. Future research should explore whether extending the training duration enhances structural brain changes and include additional control conditions to distinguish mindfulness-specific effects from expectancy biases.

In summary, our findings suggest that BMM enhances cognitive engagement by strengthening left-frontal brain activity, which is crucial for attentional control and precision performance. This provides a practical and time-efficient approach for improving focus in precision-demanding fields such as sports, gaming, and military training.

Practical applications of brief mindfulness meditation

Our findings suggest that BMM enhances cognitive engagement by increasing left-frontal brain activity, which is crucial for attentional control, decision-making, and precision tasks. While this study focused on shooting, these benefits may extend to other fields requiring similar cognitive skills. In sports like archery and dart throwing[37–39], BMM could help athletes maintain focus and execute precise movements under pressure. In esports, where sustained attention and rapid reactions are critical, BMM may reduce mental fatigue and enhance cognitive sharpness. Similarly, military and law enforcement personnel could use BMM to improve situational awareness and shooting accuracy in high-stress scenarios.

Beyond these areas, professions such as surgery and aviation, which require sustained focus and precision, may also benefit from short mindfulness sessions to enhance cognitive readiness. We recommend integrating 15-min BMM sessions before training to boost focus or after training to aid cognitive recovery, possibly combined with task-specific drills like shooting simulations for better real-world application.

While mindfulness practices have been widely adopted globally, cultural dimensions should be considered to maximize effectiveness. In collectivist cultures, emphasizing mindfulness' relational and communal benefits may improve acceptance and engagement[40], and using culturally familiar metaphors could help participants better connect with mindfulness principles[41]. Future studies should explore how BMM can be adapted to align with different cultural norms and whether such adaptations enhance its outcomes[42].

Limitations and future research directions

This study illustrated that an 18-day BMM training can notably improve shooting performance, and also showed an increased Beta/(Alpha + Theta) ratio during shooting tasks. These results suggest that mindfulness enhances cognitive engagement, potentially offering significant benefits as a performance-enhancing intervention, particularly for novices in sports where precision and mental focus are crucial.

However, several limitations should be acknowledged. First, the study was conducted with a relatively homogenous sample of healthy adults, which may limit the generalizability of findings to diverse populations. Second, while an 18-day intervention was sufficient to produce short-term improvements, the long-term sustainability of these effects remains unclear. Future studies should include follow-up assessments (e.g., 3 months, 6 months, 1 year post-intervention) to determine whether benefits persist after stopping meditation training. Third, the lack of an active control group (e.g., relaxation training, biofeedback) makes it difficult to rule out placebo effects or compare BMM with other mental training techniques. Future research should explore how BMM compares to alternative cognitive training methods and whether its effects are distinct or complementary. Fourth, this study used VR-based shooting tasks, which, while controlled and replicable, may not fully translate to real-world performance. Future work should examine how mindfulness training impacts real-world precision tasks, such as live shooting or high-stakes esports competitions. Finally, while we used the Beta/(Alpha + Theta) ratio as a cognitive engagement marker, additional neurophysiological data, such as gamma activity, could provide deeper insights into the neural mechanisms underlying decision-making and attentional control.

To address these gaps, future research should expand participant diversity, examine longer-term mindfulness interventions, include active control groups for comparison, and explore BMM's effectiveness in real-world performance settings. By refining methodologies and broadening applications, further studies can optimize BMM as a cognitive training tool for athletes, gamers, and military professionals.

Data availability

Data is provided within the manuscript or supplementary information files.

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Author contributions

All authors contributed to the study's conception and design. J. G. and X. Z. performed material preparation, data collection, and analysis. J. G. and X. Z. wrote the first draft of the manuscript. Y. W. commented on previous versions of the manuscript. Y. L. and C. J. supervised the process and acquired the foundation for this study. All authors read and approved the final manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

The studies involving human participants were reviewed and approved by the Naval Medical University Medical Ethics Committee.

Informed consent

Informed consent was obtained from all participants or their legal guardians for the publication of identifying information/images.

Additional information

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