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Characteristics of Mind Wandering during Resting State under Competitive Pressure

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Abstract

Objective: Mind wandering (MW) in athletes during competition can impair performance. Monitoring the characteristics of athletes' MW can provide scientific guidance for intervention. This study examined the behavioral and brain activation patterns that characterize MW in athletes during the resting state under competitive pressure. **Methods:** A total of 104 athletes were selected and asked to complete a resting state task containing 20 randomized thought probes while being monitored by functional near-infrared spectroscopy (fNIRS). **Results:** In the resting state, the frequency of MW was 36.2%, significantly higher in the low pressure group than in the high pressure group, and was dominated by meta-conscious MW. During MW, the left ventral lateral prefrontal cortex (L-VLPFC) and right ventral lateral prefrontal cortex (R-VLPFC) were significantly activated, and the activation of the right dorsolateral prefrontal cortex (R-DLPFC) was significantly enhanced during non-meta-conscious MW. **Conclusion:** In the resting state, the frequency of MW was higher under lower competitive pressure. The occurrence of MW was related to the L-VLPFC and R-VLPFC, the non-meta-conscious MW was related to the R-DLPFC. Future neural feedback interventions can be developed with reference to these brain activation patterns.

Keywords

Mind Wandering, Athlete, fNIRS, Resting State, Competitive Pressure

1. Introduction

Mind wandering (MW) is a common phenomenon in daily life, accounting for 30% - 50% of an individual's waking hours (Kane et al., 2007). Athletes often experience MW in training and competition (Li & Yao, 2016). MW occurs when the content of an individual's mind diverts away from the current task to self-generated thoughts and feelings, and the individual lacks control over this process (Smallwood & Schooler, 2006). It has been shown that MW can improve the positive functions of creativity (Baird et al., 2012; Jarosz et al., 2012) and future planning (Baird et al., 2011). However, MW can impair performance on cognitive tasks, such as reading (Mooneyham & Schooler, 2013) and safe driving (Derek et al., 2018). In athletes, MW can also have negative effects (Li & Yao, 2016), such as poor training, energy consumption, motor errors, and sports injuries. Therefore, detecting MW states is important for many fields, especially for learning and training (Liu et al., 2021).

To explore the cognitive neural mechanisms of MW can provide important scientific guidance for mitigating its negative effects. The most concerned brain region in MW studies is the default mode network (DMN) and the central executive network (CEN). DMN includes the ventral central prefrontal lobe, posterior cingulate cortex, and part of the temporal lobe containing the hippocampal gyrus. The higher the tendency of MW, the more active the DMN (Mason et al., 2007). However, recent studies have shown that DMN is also associated with different cognitive processes such as self-directed thinking, mindfulness, and emotion (Anticevic et al., 2012; Brewer & Garrison, 2014; Sheline et al., 2009; Zhou et al., 2019). A meta-analysis found consistent recruitment of non-DMN regions, including the medial prefrontal cortex, posterior cingulate cortex, medial temporal lobe, and bilateral subparietal lobes (Fox et al., 2015).

The DMN is insufficient to capture the neural characteristic of MW; other non-DMN regions are equally important. Cognitive neural studies of MW need to emphasize regions and networks beyond the DMN. The DMN is controlled by the central executive network (CEN), a task network that includes the dorsolateral prefrontal cortex, posterior parietal cortex, and intraparietal sulcus (Seeley et al., 2007). These two networks interact with each other in healthy adults (Fox et al., 2005). At the cognitive level, MW occurs when executive function is less demanding, while more demanding tasks inhibit it. Despite these structural and functional differences, neuroimaging studies show that MW involves both the DMN and the CEN (Christoff et al., 2009). Meta-analyses mapping the brain activation patterns of executive function sub-components show that the activation areas are mainly in the bilateral prefrontal cortex (PFC) (Niendam et al., 2012). The PFC is the most important brain region for executive functions and is a main region of interest (ROI) in neuroimaging studies (Byun et al., 2014). Recent studies have demonstrated differences in cerebral blood oxygen between MW and concentration in the PFC (Liu et al., 2021).

Early studies directly define the resting state as MW. Researchers asked subjects to complete a tone detection task and a resting state task. They found a higher frequency of MW during the resting state task than during the tone detection task, suggesting that the resting state represents MW (Binder et al., 1999). Christoff et al. (2004) also equated the resting state with MW. They compared the resting state with simple left-handed and right-handed tasks and found that the resting state activates more brain regions, such as the temporal pole cortex, parahippocampal gyrus, rostral lateral prefrontal cortex, parietal lobe, and visual processing cortex (Christoff et al., 2004). Another study analyzing the correlation between reading comprehension and resting state finds that poor reading performance is associated with MW when posterior cingulate gyrus and ventral striatal connections are strengthened (Smallwood et al., 2013). The above studies equate the resting state with MW, but the nature of the task states chosen for comparison with the resting state differs, leading to inconsistent results. Although such studies explain the mechanism of MW to an extent, they do not clearly define the differences between resting state and MW. The present study considers the resting state as a task situation, and MW occurring throughout this situation is captured through a randomized probe. This method provides a more accurate response to the behavioral and brain cognitive characteristics during MW in the resting state.

The cognitive characteristics of MW differ depending on its content. MW can be categorized into meta-conscious and non-meta-conscious (Smallwood et al., 2012). Researchers used a probe-based detection method to capture three states during task processing: focus on the task, awareness of MW (meta-conscious MW), and completely unawareness of MW (non-meta-conscious MW) (Christoff, 2012; Christoff et al., 2009). They found that more DMN and CEN regions (including the dorsal anterior cingulate gyrus and lateral prefrontal cortex) are activated during non-meta-conscious MW. In contrast, although meta-conscious MW also activated both brain networks, fewer brain regions were activated. This finding highlights the importance of in-depth comparison of the neural mechanisms underlying different types of MW.

Functional near-infrared spectroscopy (fNIRS) is a routine functional brain imaging tool that utilizes near-infrared light to detect cortical activity. It is a portable, low-cost, non-invasive neuroimaging technique with high spatial resolution, making it a promising research tool (Strait & Scheutz, 2014). The most obvious advantage of fNIRS is its high ecological validity, allowing brain imaging in nearly natural situations. fNIRS is less sensitive to head and limb shaking than fMRI, so subjects can blink, speak, and move appropriately during the experiment. fNIRS has been successfully used to monitor attentional state (Harrivel et al., 2013), alertness (Helton et al., 2013; Warm et al., 2007), and MW (Durantin et al., 2015).

In conclusion, the phenomenon of MW in athletes will have negative effects on performance, and exploring the neural mechanism will provide scientific basis for intervening in the occurrence of MW. The present study used fNIRS to simulate the frequency and content characteristics of MW in athletes and the corresponding fNIRS characteristics of the prefrontal cortex under simulated competitive pressure.

2. Materials and Methods

2.1. Participants

A total of 104 athletes (50 in the low pressure group and 54 in the high pressure group) participated in the experiment, with 48 males and 56 females; aged 18 - 30 years old, $M = 21.34$, $SD = 2.59$. Years of training ranged from 1 - 22 years, $M = 6.00$, $SD = 3.41$. 33 athletes were in the physical dominant category, and 71 athletes were in the skill dominant category. Specific sporting events included table tennis, basketball, volleyball, badminton, track and field, tennis, gymnastics, aerobics, swimming, soccer, and skating. The inclusion criteria for participants are as follows:

1) 18 years of age or older, more than one year of training, and experience in competitive sports
2) Right-handed
3) Native Chinese speaker
4) Normal or corrected vision
5) No history of psychiatric illness
6) No participation in similar experiments

Subjects who met the inclusion criteria were also asked to avoid stimulating beverages, hormone drugs, and strenuous exercise. Female subjects were asked not to wear makeup before the experiment. Participants were informed of the precautions related to the experiment in advance and signed an informed consent form. The experiment took place at the Laboratory of Sport Psychology, Hebei Normal University. It was approved by the Ethics Committee of Hebei Normal University (No. 2023LLSC031).

2.2. Experimental Equipment and fNIRS Test

A portable and wearable fNIRS device (NIRSIT, OBALAB) was used for the experiments. This device allows for wireless dissemination of data and monitoring of cerebral blood oxygenation changes (HbO) via a computer or tablet. It features 24 light sources, 32 detectors, and 204 channels. In this study, 48 channels were used, and the distance between the light source and detector was 3 cm to achieve optimal spatial resolution. The prefrontal regions covered by this device include the dorsolateral prefrontal cortex (DLPFC), ventral lateral prefrontal cortex (VLPFC), frontal polar prefrontal cortex (FPC), and orbitofrontal cortex (OFC). Figure 1 shows the location of the channels corresponding to the prefrontal brain regions. According to previous studies, the DLPFC and VLPFC were the focal areas for studying mind wandering. Therefore, the four ROIs in this study were right dorsolateral prefrontal cortex (R-DLPFC), right ventral lateral prefrontal cortex (R-VLPFC), left dorsolateral prefrontal cortex (L-DLPFC), and left ventral lateral prefrontal cortex (L-VLPFC).

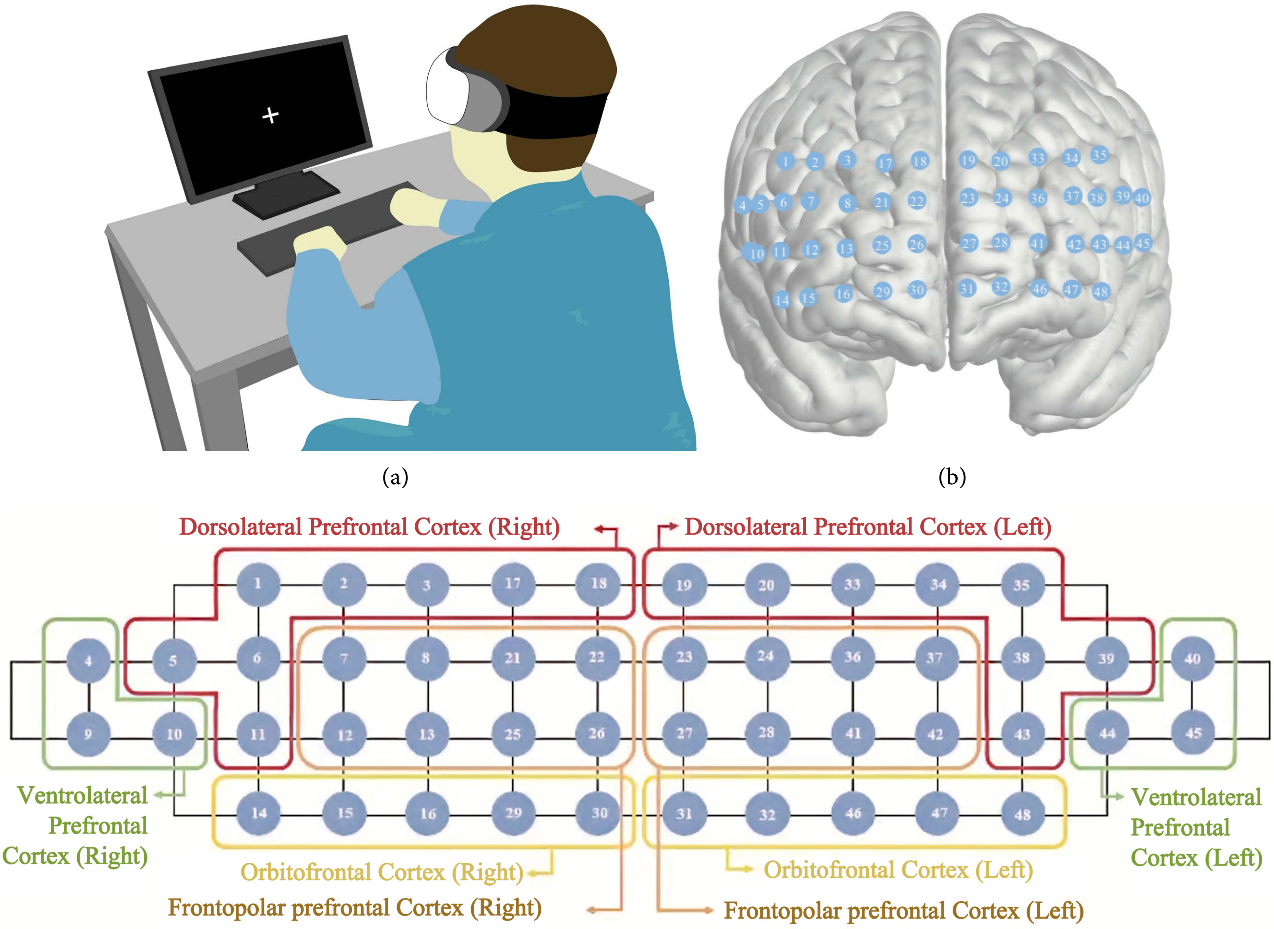
2.3. Experimental Procedures

All athletes in the high pressure group will have a competition within the last three months, while athletes in the low pressure group will have no competition. In addition, the high pressure group was required to simulate two factors in the competition during the experiment:

1) Spectators. Three experimenters watched and completed the entire experiment like spectators in the competition.

2) Video recording. The entire experiment was recorded with a camera.

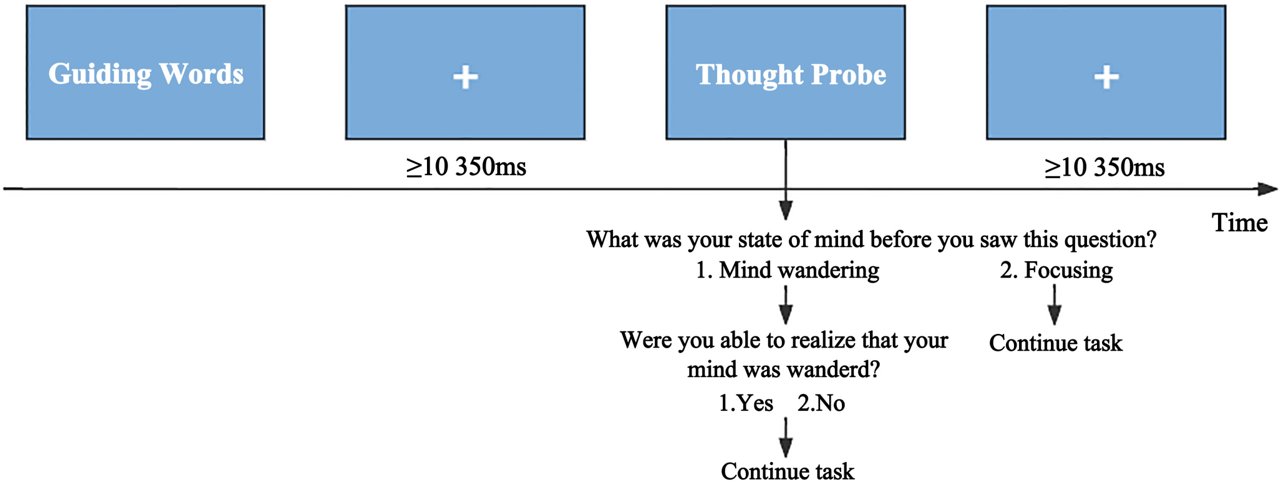
The experimental program was written in Eprime 3.0. During the experiment, participants were asked to stay awake while focusing on the "+" in the middle of the black screen. The experimental program sampled thoughts at random time intervals greater than or equal to 10,350 ms. The 10s before the appearance of the thought probe was the sampling time window of the marker (the length of time selected for analyzing the data was 3 s before the appearance of the time window to 3 s after the end of the time window, for a total of 16 s). The experiment consisted of a practice phase and a formal experimental phase. The practice phase consisted of two thought samples, and the data from this phase were excluded in subsequent statistical analysis. The formal experiment phase included 20 random thought probes, and participants were asked to answer the thought probe questions. The questions included "What is the state of mind before seeing this question?" (MW or focusing). If "MW" was chosen, the following question was "Were you aware of the MW?" The experiment lasted about 15 min. The procedure of the experimental task is shown in **Figure 1**.



(a)

(b)

(c)



(d)

Figure 1. Description of the experiment: (a) Simulation diagram of athletes performing resting state experimental tasks. Wireless NIRSIT was used to measure brain activation. (b) Optode locations covering the frontal cortex (24 sources and 32 detectors). Red circles denote sources, and blue circles represent detectors. (c) Corresponding locations of channels and prefrontal brain regions. (d) Experimental procedure.

2.4. Data Analysis

For the behavioral data, item fit test and percentage homogeneity test were used. According to the adjusted standardized residual value, the critical value for a 0.05 significance level was 1.96 and 2.58 for a 0.01 significance in the post-comparison of percentage homogeneity (Haberman, 1978). fNIRS data were collected through NIRSIT_PC, and the raw data were preliminary processed using NIRSIT. The analysis steps are as follows:

1) Import the raw data, the electrode placement position, and the marker recording file.

2) Utilize the gyro tester and accelerometer embedded in the head unit by the NIRSIT to exclude and compensate for motion artifacts.

3) Delete data segments irrelevant to the experiment and use band-pass filtering (including low and high cut-off bands) to remove frequency components smaller than 0.01 Hz and larger than 0.09 Hz.

4) Use the modified Beer-Lambert law (Cope et al., 1988) to calculate the mean value of oxyhe-moglobin (HbO) concentration in the period prior to the emergence of each probe.

5) Import the processed data into SPSS and analyze them using repeat-ed-measures analysis of variance (ANOVA). Correct statistics not meeting the spherical test with Greenhouse-Geisser correction, adjusting the degrees of freedom and *p*-value by the Bonferroni method.

3. Results

3.1. Manipulation Check of Competitive Pressure

The score of MRF (Mental Readiness Form) scale represents the pressure level of athletes (Krane, 1994). A higher score on this scale represents a lower level of competitive pressure. An independent samples t-test on the scores of this scale in the high and low pressure groups showed that the scores of the low pressure group were significantly higher than those of the high pressure group, $t_{(102)} = 2.958$, $p = 0.004$, $d = 0.586$. These results indicated that the manipulation check of competitive pressure was successful.

3.2. Behavioral Characteristics of Athletes' MW

The experiment sampled the resting state of mind of 104 effective participants. Each participant was required to answer 20 random thought probe questions, resulting in 2080 thought samples. Among them, 753 probes reported MW, accounting for 36.2% of the total number of probes. The fitness test of the item showed a significant difference in the distribution of the number of people who chose MW versus focusing ($\chi^2 = 158.40$, $p = 0.000$).

A percentage homogeneity test explored whether a significant difference existed in the percentage of times athletes with different pressure types chose "MW" and "focusing". The results of the analysis are presented in **Table 1**. A significant difference was observed between the percentage of times athletes with different pressure types (low and high pressure) chose "MW" and "focusing" ($\chi^2 = 52.02$, $p = 0.000$). Post-hoc comparisons revealed that the adjusted standardized residual values reached the 0.01 significance level of 7.2 for the low pressure group and −7.2 for the high pressure group for the "MW" option and −7.2 for the low pressure group and 7.2 for the high pressure group for the "focusing" option. This outcome indicated a significant difference between the low and high pressure groups. The percentage of low pressure group choosing "MW" was significantly higher than the percentage of high pressure group. The percentage of low pressure group choosing "focusing" was significantly lower than the percentage of high pressure group.

Table 1. Number and chi-square test of probe selection by athletes under different pressure types.

Response variable	Design variable	Pressure types		χ^2	p	Post-hoc comparison
		Low (A)	High (B)			
MW	Number	441	312	52.02	0.000	A > B
	Percentage	21.2	15			
Focusing	Number	559	768			A < B
	Percentage	26.9	36.9			
Meta-consciousness MW	Number	336	271	13.31	0.000	A > B
	Percentage	44.6	36			
Non-meta-consciousness MW	Number	105	41			A > B
	Percentage	13.9	5.4			

Note: MW (mind wandering).

Another percentage homogeneity test explored whether a significant difference existed in the percentage of MW's meta-consciousness features among athletes of different pressure types. The analysis results, shown in **Table 1**, indicated the percentage of times athletes of different pressure types (low and high pressure) chose "meta-conscious MW" and "non-meta-conscious MW". A significant difference was observed between the percentages ($\chi^2 = 13.31$, $p = 0.000$). Post-hoc comparisons showed that the adjusted standardized residuals reached the 0.01 significance level at −3.6 for the low pressure group and 3.6 for the high pressure group for the "Meta-consciousness MW" option and 3.6 for the low pressure group and −3.6 for the high pressure group for the "Non-meta-consciousness MW" option. Specifically, the percentage of the low pressure group choosing the "Meta-consciousness MW" was significantly higher than the percentage of the high pressure group. The percentage of the low pressure group choosing the "Non-meta-consciousness MW" was significantly higher than the percentage of the high pressure group

3.3. fNIRS Characteristics of MW in Athletes

During fNIRS data processing, the values of overlapping channels, the average of neighboring channels, or interpolation were used to replace the rejected channels, and if there were still more than five rejected channels for that subject after processing by the three methods mentioned above, 8 subjects were excluded. In addition, some sub-jects chose either "MW" or "focusing" in their thinking type. Data from 11 subjects who did not experience both the two thought states were regarded invalid. After applying above criterion, 85 subjects remained. An independent samples t-test of the 85 athletes' scores on the MRF scale showed that the low pressure group scored significantly higher than the high pressure group, $t_{(83)} = 3.116$, $p = 0.003$, $d = 0.684$. **Table 2** presents the descriptive statistics for brain region activation based on the pressure type and thought type.

Table 2. Descriptive statistics of brain regional activation under different experimental conditions (n = 85).

Brain region	Pressure types		Thinking types		MW types	
	Low	High	Focusing	MW	Meta-consciousness MW	Non-meta-consciousness MW
R-DLPFC	1.196 ± 5.606	0.023 ± 4.018	0.383 ± 7.979	1.980 ± 7.504	−0.356 ± 16.610	7.225 ± 12.462
R-VLPFC	−3.189 ± 5.795	−1.007 ± 6.447	−3.827 ± 11.006	0.692 ± 8.812	2.351 ± 14.017	1.084 ± 21.781
L-DLPFC	0.171 ± 5.394	−0.503 ± 4.354	−0.639 ± 8.256	1.418 ± 8.725	1.739 ± 9.066	3.124 ± 18.599
L-VLPFC	−3.267 ± 9.248	−2.254 ± 7.879	−5.635 ± 12.440	−0.092 ± 15.715	0.753 ± 19.701	−0.186 ± 27.559

Note: Units are μmol/L; MW (mind wandering).

3.4. fNIRS Characteristics of Athletes during MW/Focusing

To examine the effects of competitive pressure and MW on the HbO signal in 4 ROIs, we carried out a 2 (pressure type: low pressure, high pressure) × 2 (thought type: MW, focusing) repeated-measures ANOVA for each ROI. The dependent variable was the HbO signal.

On the R-DLPFC, the main effect of pressure type was not significant [$F_{(1,83)} = 1.268$, $p = 0.263$, $\eta_p^2 = 0.015$]. The main effect of thought type was also not significant [$F_{(1,83)} = 1.653$, $p = 0.202$, $\eta_p^2 = 0.020$]. The interaction effect of pressure type × thought type was not significant [$F_{(1,83)} = 0.267$, $p = 0.607$, $\eta_p^2 = 0.003$].

On the R-VLPFC, the main effect of pressure type was not significant [$F_{(1,83)} = 0.811$, $p = 0.370$, $\eta_p^2 = 0.010$]. The main effect of thought type was significant [$F_{(1,83)} = 4.130$, $p = 0.045$, $\eta_p^2 = 0.047$] (Figure 2). Multiple comparisons revealed that HbO was significantly greater in the MW state than in the focusing state ($p = 0.045$). The interaction effect of pressure type × thought type was not significant [$F_{(1,83)} = 0.753$, $p = 0.388$, $\eta_p^2 = 0.009$].

On the L-DLPFC, the main effect of pressure type [$F_{(1,83)} = 1.336$, $p = 0.251$, $\eta_p^2 = 0.016$] and thought type [$F_{(1,83)} = 2.354$, $p = 0.129$, $\eta_p^2 = 0.028$] was not significant. The interaction effect of pressure type × thought type was not significant [$F_{(1,83)} = 0.390$, $p = 0.534$, $\eta_p^2 = 0.005$].

On the L-VLPFC, the main effect of pressure type was not significant [$F_{(1,83)} = 0.354$, $p = 0.553$, $\eta_p^2 = 0.004$]. The main effect of thought type was significant [$F_{(1,83)} = 5.907$, $p = 0.017$, $\eta_p^2 = 0.066$] (Figure 2). Multiple comparisons revealed that HbO was significantly greater in the MW state than in the focusing state ($p = 0.017$). The interaction effect of pressure type × thought type was not significant [$F_{(1,83)} = 0.033$, $p = 0.856$, $\eta_p^2 = 0.000$].

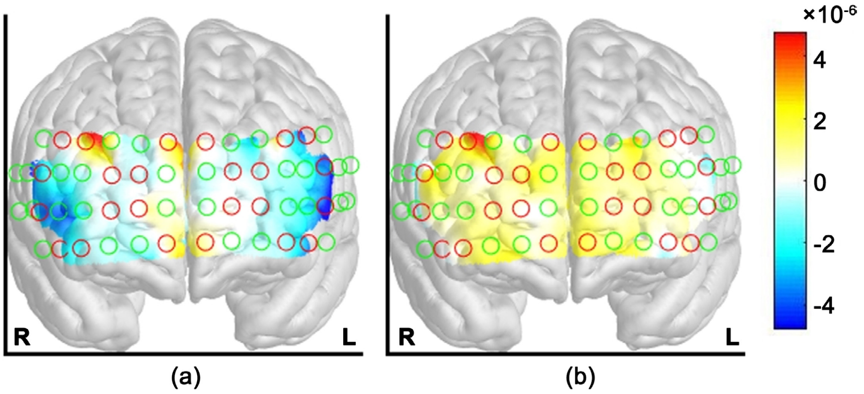


Figure 2. Comparison of prefrontal activation in the focusing and mind wandering conditions. Note: (a) Focusing; (b) Mind wandering. The redder the color is, the higher the activation level is.

3.5. fNIRS Characteristics of Athletes with/without Meta-Conscious MW

To examine the effects of competitive pressure and meta-conscious MW on the HbO signals in the 4 ROIs, we performed a 2 (pressure type: low, high) × 2 (meta-consciousness: with/without meta-conscious MW) repeated-measures ANOVA for each ROI. The dependent variable was the HbO signal.

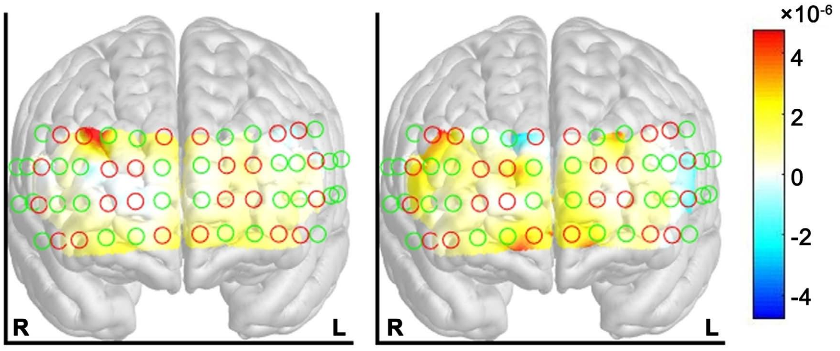
Some subjects chose either meta-conscious MW or non-meta-conscious MW. Data from 85 subjects who did not experience both the two MW types were regarded invalid. By applying this criterion, 46 subjects remained. An independent samples t-test on their scores on the MRF scale showed that the low pressure group scored significantly higher than the high pressure group, $t_{(44)} = 2.198$, $p = 0.033$, $d = 0.663$.

On the R-DLPFC, the main effect of pressure type was not significant [$F_{(1,44)} = 0.721$, $p = 0.400$, $\eta_p^2 = 0.016$]. The main effect of meta-consciousness characteristics was significant [$F_{(1,44)} = 4.420$, $p = 0.041$, $\eta_p^2 = 0.091$] (**Figure 3**). Multiple comparisons revealed that HbO was significantly greater in the state of non-meta-conscious MW than in the state of meta-conscious MW state ($p = 0.041$). The interaction effect of pressure type × meta-consciousness was not significant [$F_{(1,44)} = 1.601$, $p = 0.212$, $\eta_p^2 = 0.035$].

On the R-VLPFC, the main effect of pressure type was not significant [$F_{(1,44)} = 0.001$， $p = 0.980$, $\eta_p^2 = 0.000$]. The main effect of meta-consciousness characteristics was also not significant [$F_{(1,44)} = 0.309$, $p = 0.581$, $\eta_p^2 = 0.007$]. The interaction effect of pressure type × meta-consciousness characteristics was not significant [$F_{(1,44)} = 1.232$, $p = 0.273$, $\eta_p^2 = 0.027$].

On the L-DLPFC, the main effect of pressure type was not significant [$F_{(1,44)} = 0.891$, $p = 0.350$, $\eta_p^2 = 0.020$], and the main effect of meta-consciousness characteristics was not significant [$F_{(1,44)} = 0.163$, $p = 0.689$, $\eta_p^2 = 0.004$]. The interaction effect of pressure type × meta-consciousness characteristics was not significant [$F_{(1,44)} = 0.098$, $p = 0.755$, $\eta_p^2 = 0.002$].

On the L-VLPFC, the main effect of pressure type [$F_{(1,44)} = 0.088$, $p = 0.769$, $\eta_p^2 = 0.002$] and meta-consciousness characteristics [$F_{(1,44)} = 0.046$, $p = 0.832$, $\eta_p^2 = 0.001$] were not significant. The interaction effect of pressure type × meta-consciousness characteristics was not significant [$F_{(1,44)} = 0.043$, $p = 0.837$, $\eta_p^2 = 0.001$].



(a) (b)

Figure 3. Comparison of prefrontal activation under different conditions of mind wandering content features. Note: (a) Non-meta-conscious mind wandering; (b) Meta-conscious mind wandering; the redder the color, the higher the activation level.

4. Discussion

This study explored the behavioral and brain activation characteristics of athletes under competitive pressure who experience MW in the resting state. The results showed a 36.2% frequency of MW in athletes under competitive pressure. MW in athletes was dominantly meta-conscious. Meta-conscious MW and non-meta-conscious MW occurred more frequently in athletes under low pressure than in those under high pressure.

4.1. Behavioral Characteristics of MW

The 36.2% frequency of MW is consistent with the 30% - 50% range reported for non-athletes (Kane et al., 2007). Interestingly, athletes under low pressure experienced MW significantly more often than those under high pressure. This result partly supports previous qualitative research on athletes that MW occurs frequently when athletes feel relaxed during training (Li, 2017). Researchers commonly use competitive anxiety levels to represent the degree of pressure. "Processing Efficiency Theory" suggests that anxiety consumes cognitive resources, resulting in insufficient resources allocated to the task at hand and affecting performance (Michael et al., 1992). The "Decoupling Hypothesis" suggests that MW also consumes cognitive resources (Smallwood, 2010; Smallwood & Schooler, 2006). Both competitive pressure and MW take up cognitive resources. Combining these two theories, athletes who take up fewer cognitive resources under low competitive pressure have more cognitive resources to spend on MW, which may account for the higher frequency of MW. However, some studies found that the frequency of MW occurs relatively more during high anxiety (Smallwood et al., 2007; Wang, 2011). The reason for the contradictory findings may be the inconsistency in the assessment tools of anxiety chosen by the researchers. In addition, the relationship between MW and anxiety may not be linear, but rather a U-shaped nonlinear. That is, when the level of anxiety is lowest or highest, the frequency of MW is the highest. When anxiety is at a moderate level, the frequency of MW is the lowest. The above speculations on the relationship between anxiety and MW need to be verified by future studies. Overall, competitive pressure affects the frequency of MW in athletes. Future MW interventions can regulate the frequency of MW in athletes by adjusting the level of competitive pressure.

4.2. Brain Activation Characteristics of MW

In the present study, we found that MW occurred in athletes in the resting state with significantly higher HbO activation on the R-VLPFC and L-VLPFC relative to focusing, but was not affected by competitive pressure. These results are similar to those of previous research showing that activation of vmPFC is positively correlated with MW (Andrews-Hanna et al., 2010; Sormaz et al., 2018). The PFC is the most important brain region for executive function (Byun et al., 2014), and it activates during MW. The "Failure of Control Hypothesis" suggests that as soon as cognitive control fails or MW occurs, executive resources inhibit MW and refocus attention on the current task (Mcvay & Kane, 2010). At the same time, R-VLPFC was found to be extensively involved in response inhibition control tasks, suggesting that the VLPFC is a brain region with general inhibitory functions (Aron et al., 2004). Therefore, the results of the present study showed a significant increase on the R-VLPFC and L-VLPFC during MW, which may be a process of executive resource inhibition of MW. It is noteworthy that the brain activation of the athletes at this time was not affected by competitive pressure. The possible reason for this is that we only analyzed the difference between MW and focusing. Whereas competitive pressure belongs to emotional features, the content of MW were not categorized here for emotional potency. If the content of MW is categorized for emotional potency, different results may be found.

Brain activation analysis revealed that non-meta-conscious MW significantly activated HbO levels in the R-DLPFC compared with meta-conscious MW. This result is similar to those of previous studies. Stimulating the DLPFC with transcranial direct current stimulation impairs the meta-conscious abilities of the subjects (Rounis et al., 2010) and modulates the frequency of MW, indicating the important role of the region in MW (Axelrod et al., 2015). Furthermore, fMRI studies reveal that MW activates not only regions related to the DMN but also some regions of the executive system, including the DLPFC. Interestingly, higher neural engagement of the DMN and executive networks occurs when individuals are unaware of MW, suggesting a deeper degree of MW (Christoff et al., 2009; Stawarczyk et al., 2011). These results support the "Uncoupling Hypothesis" that the brain regions responsible for MW consume cognitive resources (Smallwood & Schooler, 2006). The brain regions activated by MW differ on the basis of content characteristics. Seli et al. (2018) advocated understanding MW using the principle of family resemblance, recognizing it as a multidimensional and heterogeneous concept. Athletes' MW during competition includes seven dimensions, namely, temporal directionality, emotional potency, intentionality, relationship to the competition, depth, duration, and meta-consciousness (Li et al., 2024). Irving et al. (2020) argued that different dimensions of MW have varying weights, with some MW examples more typical than others. Therefore, future research should consider the weighting of other dimensions when exploring MW in athletes.

In summary, MW in athletes during the resting state is associated with failures of executive control, which can also consume cognitive resources. Evidence suggests that individuals prone to MW exhibit an atypical organization of resting-state brain activity, which may translate into a reduction in the resources required to maintain attentional control under task-relevant conditions (Krukow & Jonak, 2022). In addition, a network of resting-state functions correlates with performance in complex visuomotor tasks (Penalver-Andres et al., 2024). It has important implications for training and competition in sports. The rapidly changing context in the competition requires athletes to cope with many external stimuli, and MW can consume cognitive resources, negatively affecting the athlete's decision making and performance (Li et al., 2024).

5. Limitation and Future Direction

MW has implicit characteristics, posing difficulties in its measurement. To measure MW, this study used "Experience Sampling" that researchers randomly placed probes during the task to ask individuals about their state of mind (whether or not they wandered). Studies show that the "Experience Sampling" method minimally affects MW (Wiemers & Redick, 2019) and that randomly placed thought probes can capture MW without meta-consciousness. However, this method also has limitations; the thought probes interrupt natural task processes and MW (Mooneyham & Schooler, 2013). Future research can consider a combination of post-task questionnaire and thought probes.

In addition, this study focused on MW during the resting state, information about MW's effect on task performance was not obtained. Future experimental studies can be conducted by applying cognitive tasks or motor tasks in sport contexts to obtain the effect of MW on task performance. Given the multidimensional nature of MW, a more detailed and precise delineation of its different forms is needed (Seli et al., 2018). Some researchers also proposed the importance of a more comprehensive understanding of the brain mechanisms underpinning the different contents of MW (Deng et al., 2019). MW in competitions may affect sporting performance differently depending on the contents of MW (Li et al., 2024). Therefore, accurately measuring the different contents of MW is a scientific problem that warrants future investigation.

6. Conclusion

To explore the characteristics of MW in athletes under competitive pressure is an important reference to reduce the possible negative effects of MW in sports. Our findings revealed that the frequency of MW was higher in athletes under low levels of competitive pressure. In addition, the occurrence of MW was related to the VLPFC, and non-meta-conscious MW was related to the R-DLPFC. These results indicate that MW is also a common phenomenon in athletes. More importantly, different types of MW have different brain activation patterns. It reminds us of the importance of distinguishing between MW types. In addition, whether different MW types have different effects on performance is a practical question worth further study. The results provide the foundation for the study of different MW types. This will make an important contribution to the development of competitive sports.

Authors' Contributions

JL conceived of the study, analyzed the data and drafted manuscript. JL and YM have collected the data and revised the manuscript. Both authors contributed to the article and approved the submitted version.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Hebei Normal University (No. 2023LLSC031).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflicts of Interest

We declare this research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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