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Overactivation of the Reward System and Deficient Inhibition in Exercise Addiction

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ABSTRACT

HUANG, Q., J. HUANG, Y. CHEN, D. LIN, S. XU, J. WEI, C. QI, and X. XU. Overactivation of the Reward System and Deficient Inhibition in Exercise Addiction. *Med. Sci. Sports Exerc.*, Vol. 51, No. 9, pp. 1918–1927, 2019. **Purpose:** Behavior studies have found that exercise addiction is associated with high impulsivity. In other addictions, neural mechanisms of impulsivity reflect abnormalities in the reward and inhibition systems. In this study, we determined whether abnormalities existed in the reward and inhibition systems of exercise addicts. **Methods:** Three groups of male participants (15 exercise addicts, 18 regular exercisers, and 16 exercise avoiders) completed the Mini International Personality Item Pool (Mini-IPIP), the classic go/no-go task, and the exercise-related go/no-go task. Event-related potentials (ERP) were recorded during the go/no-go tasks, and correctly performed trials were analyzed. **Results:** Exercise addicts scored lower for extraversion and higher for neuroticism, reflecting a poor capacity for emotional regulation and impulse control, and had larger N2 and P3d amplitudes during the exercise-related go/no-go task. Exercise addicts and exercise avoiders demonstrated impaired accuracy in the exercise-related go/no-go task and had larger N2 amplitudes compared with regular exercisers during the letter–digit go/no-go task. Exercise addicts and regular exercisers showed larger Go-N1 and Go-P2 amplitudes compared with exercise avoiders during the exercise-related go/no-go task. Exercisers (exercise addicts and regular exercisers) demonstrated higher activation in response to exercise-related stimuli as reflected by larger N1 and P2, and addicts (exercise addicts) demonstrated poorer inhibition as reflected by larger N2 and P3d amplitudes. Go-N1 and Go-P2 were significantly correlated with no-go accuracy in exercise-related task. **Conclusions:** Exercise addicts scored higher for the neuroticism personality trait and exhibited overactivation of the reward system and underactivation of the inhibition system. Overactivation of the reward system may be related to long-term exposure to exercise. Underactivation of the inhibition system may be a crucial factor in exercise addiction.
Key Words: EXERCISE ADDICTION, IMPULSIVITY, ERP, GO/NO-GO

Regular physical exercise contributes to the prevention of several chronic diseases and is associated with a reduced risk of premature death (1). For some individuals, however, habitual exercise becomes a maladaptive behavior and may contribute to the development of exercise addiction (2). Exercise addiction has been described since the 1970s and is characterized by increasing exercise amounts, tolerance to exercise, and withdrawal symptoms, as well as continuing to exercise despite pain or injury (2). Exercise addiction has negative effects on both physical and mental health.

Exercise addiction is broadly classified as a behavioral addiction, whereby an individual becomes addicted to the benefits and rewards of their own activity (3), although this classification is not currently included in the *Diagnostic and Statistical Manual of Mental Disorders*. Previous study showed that higher impulsivity was tightly linked to addiction (4). Addicts tend to repetitively and habitually lose control of their behavior and present the impulsivity trait on personality tests (5). Some studies even support the proposal that addiction is characterized by impulse control impairment (4). Impulsivity-related deficits are a central feature in the etiology of addiction (6). As a behavioral addiction, exercise addiction is also related to high impulsivity (7). In addition, studies have found that exercise addicts have significantly higher neuroticism scores compared with nonaddicts (7). A higher neuroticism score indicates greater difficulty in emotion regulation, leading to higher excitability and more impulsive behavior (8). However, personality differences between exercise addicts and regular exercisers have never been reported.

According to the dual-process model, impulsivity and decision making are regulated by the reward system and inhibition system (9). The reward system is also known as the automatic–affective

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system and mainly relies on limbic–striatal areas to drive impulsive and automatic behaviors (10). History studies have found that addicts exhibit overactivation of the reward system as reflected by greater reward-seeking behavior (11–13). Researchers have found that addicts display increased sensitivities to addiction-related cues as revealed by increased activities in the prefrontal, limbic, and striatal regions among individuals with alcohol use disorders exposed to alcohol-related cues (11) and among problem Internet users exposed to Internet-related cues (12), as well as increased N1, P2, and late positive complex amplitudes among Internet gaming disorders exposed to Internet-related cues (13).

The inhibition system, also known as the reflective system, mainly relies on orbitofrontal–dorsolateral cortices and is involved in thoughtful, controlled conduct (9). Impaired inhibition is a component of impulsivity and has been verified as an important feature of addiction by a series of event-related potential (ERP) studies on addictions (14). Using go/no-go tasks, studies have found that addicts such as problem Internet users showed reduced N2 and P3 amplitudes in no-go trials compared with healthy controls (14). According to Dong et al. (15), the frontal N2 component reflects an early subprocess of response inhibition, namely, conflict detection, and the frontal–central P3 component reflects the late decision process to inhibit motor responses (16). Notably, in correctly inhibited trials, the larger ERP amplitudes corresponded to greater cognitive resource requirements to elicit the correct response, which might be impaired by weaker inhibitory control (17).

The combination of overactivation of the reward system and underactivation of the reflective system affects decision making among addicts and causes them to lose control (16,17). Therefore, we investigate the role of the dual-process model in decision making in exercise addicts and propose the first hypothesis that exercise addicts exhibit overactivation of the reward system and underactivation of the reflective system.

Increased sensitivity of the reward system and impaired inhibition are considered important factors in loss of control in addiction. However, some researchers have reached different complex conclusions when comparing differences among addicts, problem users (nonaddicts who use addictive substances or engage in addictive behaviors), and nonusers. Brevers et al. (18) and Ersche et al. (19) found that both addicts and problem users showed higher sensitivity to rewards than nonusers, but only addicts showed abnormally low performance on response inhibition tasks. The authors argued that two potential mechanisms account for impulsive behaviors in addicts: one refers to preexisting individual differences within impulse inhibition, and the other refers to the effect of exposure to an addictive environment. Considering this argument, we suggest a second hypothesis that the overactivation of the reward system among exercise addicts with long-term exposure to exercise increases their sensitivity to exercise-related stimuli and that poor inhibition is a risk factor for developing exercise addiction.

In the present study, we used an exercise-related go/no-go task and a classic letter–digit go/no-go task to observe the mechanisms of the reward and inhibition systems. In addition to behavioral measures, ERP values during the go/no-go tasks were extracted to determine the brain correlates of impulsivity in exercise addiction. Moreover, to clarify whether overactivation of the reward system is related to exposure to exercise, we divided the participants into three independent groups: exercise addicts, regular exercisers (exercisers but nonaddicts), and exercise avoiders (nonexercisers). We predicted that exercisers (exercise addicts and regular exercisers) would be more sensitive to exercise-related stimuli than exercise avoiders and that exercisers would exhibit shorter reaction times (RT) in the go task compared with exercise avoiders, and exercise addicts would exhibit lower accuracy (ACC) in impulse no-go task compared with nonaddicts (regular exercisers and exercise avoiders). Considering the absence of personality differences among the three groups, we compared the three groups based on the Mini International Personality Item Pool (Mini-IPIP) scores (20).

METHODS

Participants

Participants were recruited from Wuhan Sports University and surrounding gyms. After a comprehensive description of the methods and procedures involved, written informed consent was obtained. All participants were required to meet the following inclusion criteria: 1) native Chinese speaker, 2) male, 3) right-handed, 4) normal or corrected-to-normal vision, and 5) no history of any psychiatric disease or disorder. Next, the participants were prescreened with the Exercise Addiction Inventory (EAI) and a self-compiled exercise level questionnaire and assigned to one of three groups: 1) the exercise addiction group (EAI score ≥24 (21)), 2) the regular exercise group (EAI score <24, exercise duration ≥12 months, exercise frequency ≥3 times per week, and session duration ≥30 min), and 3) the exercise avoidance group (EAI score <24, exercise level did not meet the conditions of regular exercise). The final sample included 49 participants between 18 and 26 yr old. The characteristics of the exercise addiction group, regular exercise group, and exercise avoidance group are shown in Table 1.

Measurement Methods

EAI. The Chinese version (22) of the six-item EAI (21) was used to assess exercise addiction. The EAI is rated on a 5-point Likert scale, ranging from strongly disagree (1) to strongly agree (5). The total score was calculated and ranged from 6 to 30. The EAI uses a cutoff of 24 to identify a risk of exercise addiction. The internal reliability (Cronbach's alpha) of exercise addiction was 0.84, and the retest reliability was 0.86.

Self-compiled exercise level questionnaire. The participants reported the duration of regular exercise (<6 months, 6 months–1 yr, 1–2 yr, and >2 yr), average weekly frequency (1, 2, 3, and ≥4 times), and the duration of their exercise sessions (<30, 30–60, 60–120, and >120 min). The participants were classified as regular exercisers if they met three conditions: engaging in exercise for at least 1 yr, a frequency of three or more sessions per week, and sessions lasting 30 min or more.

TABLE 1. Exercise data, EAI scores, Mini-IPIP scores, and behavioral data for classic and modified go/no-go tasks among the three groups.

	Exercise Addiction Group (*N* = 15)		Regular Exercise Group (*N* = 18)		Exercise Avoidance Group (*N* = 16)	
	n	Pct.	*n*	Pct.	*n*	Pct.
Duration of exercise						
<6 months	0	0	0	0	6	37.5
6 months–1 yr	1	6.7	0	0	4	25.0
1–2 yr	1	6.7	5	27.8	4	25.0
>2 yr	13	86.7	13	72.2	2	12.5
Weekly frequency						
1 time per week	0	0	0	0	3	18.8
2 times per week	0	0	0	0	8	50.0
3 times per week	5	33.3	5	27.8	3	18.8
≥4 times per week	10	66.7	15	72.2	2	12.5
Session duration						
<30 min	0	0	0	0	5	31.2
30–60 min	0	0	3	16.6	8	50.0
60–120 min	8	53.3	10	55.6	3	18.8
>120 min	7	46.7	5	27.8	0	0

	Mean ± SD	Mean ± SD	Mean ± SD	$F_{2,\ 46}$
Age (yr)	22.73 ± 2.96	22.50 ± 2.20	21.94 ± 2.26	0.429
EAI score	25 ± 0.93	19.78 ± 2.00	17.81 ± 3.56	27.558 (EAd > RE, EAd > EAv)**
Mini-IPIP scale				
Extraversion	11.47 ± 2.39	13.89 ± 2.27	13.13 ± 2.63	4.174 (RE > EAd)*
Agreeableness	15.73 ± 2.25	15.83 ± 2.15	14.81 ± 2.01	1.132
Conscientiousness	13.80 ± 2.24	15.17 ± 1.58	15.38 ± 1.93	3.095
Neuroticism	13.13 ± 3.38	10.39 ± 2.35	10.56 ± 2.85	4.530 (EAd > RE, EAd > EAv)*
Openness	15.13 ± 2.45	14.78 ± 2.18	14.50 ± 1.90	0.327
Classic task				
Go RT (ms)	453.19 ± 40.78	466.03 ± 62.86	447.23 ± 50.84	0.601
Go ACC	0.999 ± 0.004	0.999 ± 0.006	1	0.893
No-go ACC	0.91 ± 0.093	0.93 ± 0.086	0.90 ± 0.077	0.438
Modified task				
Go RT (ms)	516 ± 54.02	518 ± 30.45	514 ± 53.89	0.035
Go ACC	0.99 ± 0.003	1	1	2.455
No-go ACC	0.88 ± 0.074	0.95 ± 0.036	0.90 ± 0.06	6.500**

	Fz-N1	Cz-N1	Pz-N1	Fz-P2
Classic task				
No-go ACC	0.136	0.115	0.131	–0.015
Modified task				
No-go ACC	0.315*	0.345*	0.321*	–0.494**

*$P < 0.05$.
**$P < 0.01$.

If any one of the conditions was not met, then the participant was categorized as an exercise avoider.

Personality Measure: The Mini-IPIP Scale

The Mini-IPIP scale (20) consists of five 4-item subscales corresponding to each of the five major domains of personality (extraversion, agreeableness, conscientiousness, neuroticism, and openness). Each item is a statement describing a behavior (e.g., "frequent mood swings"), and the participants were asked to indicate the extent to which each statement applied to them using a 5-point Likert-type scale ranging from strongly disagree (1) to strongly agree (5). Li et al. (23) translated this scale and showed internal consistency, with Cronbach's alpha ranging from 0.79 to 0.84 and McDonald's omega ranging from 0.73 to 0.82 for scores on each subscale.

Behavioral and EEG Measures: Go/No-Go Task

Apparatus. We used a PC with a 19-inch monitor and E-Prime software (Psychology Software Tools, Pittsburgh, PA) to control stimulus presentation and response collection and to generate and send triggers, indicating the condition of each trial for offline sorting, reduction, and analysis of EEG and behavioral data. The center of the PC screen was situated approximately 60 cm from the participants' heads at eye level. A keyboard was used to collect responses.

Design and procedure. ***Classic go/no-go task.*** The participants completed a classic go/no-go task to examine their impulse control. The task consisted of 160 trials (120 go trials and 40 no-go trials). For each trial, a fixation cross was presented on the center of the screen for 300–500 ms, followed by a letter or digit for 1500 ms. The participants were asked to press the "F" key as quickly as possible whenever the go stimulus (a letter) was presented and to withhold this response when the no-go stimulus (a digit) was presented.

Exercise-related go/no-go task. The procedure was exactly the same as in the letter go/no-go task except that the stimuli were 30 colored pictures depicting exercise behaviors (such as running, playing basketball, and other fitness activities) and 10 colored pictures selected from the Chinese Affective Picture System ((24)) depicting neutral (nonexercise-related) activities. Each picture was presented four times, with the exercise-related pictures assigned to the go trials and neutral pictures assigned to the no-go trials (160 trials total: 120 go trials and 40 no-go trials). The task order was counterbalanced across participants.

Electroencephalographic (EEG) recording and preprocessing. Continuous EEG data were recorded during the go/no-go tasks using a Brain Amp system and were digitized at a sample rate of 1000 Hz with a 24-bit A/D conversion. The 64 electrodes were arranged according to the international standard 10–20 system for electrode placement using a nylon head cap. Impedances were maintained below 5 kΩ. The participants were instructed to avoid eye movements, blinking, and body movements as much as possible and to keep their gaze on the center of the screen during task performance.

After collection, the data were re-referenced to the average of the left and right mastoids (25) and band-pass filtered with a low-pass frequency of 25 Hz and a high-pass frequency of 0.1 Hz. The continuous EEG data were manually inspected, and periods with large movement-related artifacts (eye blinks and eye movement) were removed using independent component analysis. The remaining artifacts (muscle movement and noisy electrodes) exceeding ±100 μV in amplitude were detected, and the segments containing artifacts were excluded from further analysis. Stimulus-locked epochs were then segmented from −200 ms to +1000 ms and baseline-adjusted using a 200-ms prestimulus period. Using the interpolation method, bad channels were then replaced with data from the remaining channels in "good" segments. Trials with incorrect behavioral responses were excluded from all analyses. A minimum of 28 trials for the no-go segments and 107 for the go segments were retained for further processing. Separate grand average waveforms were constructed across all participants according to task (go/no-go) and group (exercise addiction/regular exercise/exercise avoidance). If 50% or more of the segments of a participant contained artifacts, then all their data were from ERP analyses; data from two participants in the exercise addiction group were rejected from ERP analyses in the classic go/no-go task, and data from one participant in the exercise addiction group were rejected from ERP analyses in the exercise-related go/no-go task.

ERP data. On the basis of previous research (13,26), N1, N2, P2, and P3 components as well as different waves, N2d (N2 different wave), and P3d (P3 different wave) were analyzed. The N1 component was defined as the most negative amplitude within the 70- to 150-ms window poststimulus onset. The P2 component was defined as the most positive amplitude within the 120- to 250-ms window poststimulus onset. According to previous study (12), addiction-related stimuli resulted in larger N1 and P2 amplitudes at the midline electrode sites in addicts. The N2 component was defined as the most negative amplitude within the 200- to 300-ms window poststimulus onset. The P3 component was defined as the most positive amplitude within the 300- to 500-ms window poststimulus onset. The N2d component represented the difference in N2 amplitudes between go and no-go stimuli (no-go minus go). The P3d component represented the difference in P3 amplitudes between go and no-go stimuli (no-go minus go) (26). Theory-driven ERP analyses focused on the N2 and P3 components, as observed in the frontal–central electrodes, as the best potential candidates to reflect inhibition-related cognitive activity during the go/no-go task.

Statistical Analysis

Three sets of dependent variables were evaluated in this study as follows: 1) Mini-IPIP scale data, 2) behavioral data (i.e., the mean RT and ACC), and 3) ERP data. We have made the Pearson correlations of the five subscales in Mini-IPIP scale. The results showed that most of them were irrelevant to one another ($r < 0.6$). The Mini-IPIP scale and the behavioral data were analyzed using a one-way ANOVA. Repeated-measures ANOVA (rANOVA) tests were used for the ERP components (group–site interaction). Pearson correlation analyzed the relationship between the ERP components (Go-N1 and Go-P2 amplitudes on Fz, Cz, Pz, and Oz) and the no-go ACC. A two-tailed alpha level of 0.05 was used for all statistical tests, and probability values were adjusted when appropriate using the Greenhouse–Geisser epsilon correction for nonsphericity (27). Tukey HSD *post hoc* tests were applied when the alpha level was less than 0.05.

In this study, the addiction-related stimuli were the go trials of the modified task. Therefore, the N1 and P2 components were analyzed and submitted to 3 (group: exercise addiction group, regular exercise group, and exercise avoidance group) × 4 (site: Fz, Cz, Pz, and Oz (13)) rANOVA. The N2 and the P3 components were submitted to 3 (group: exercise addiction group, regular exercise group, and exercise avoidance group) × 2 (task: go and no-go) × 6 (site: FPz, FP1, FP2, Fz, Cz, and Pz (28–32)) rANOVA, and the N2d and P3d data were submitted to 3 (group: exercise addiction group, regular exercise group, and exercise avoidance group) × 6 (site: FPz, FP1, FP2, Fz, Cz, and Pz) rANOVA. Only correct responses were analyzed.

RESULTS

Exercise Addicts Score Highly for Neuroticism on the Mini-IPIP Scale

We first explored whether exercise addicts displayed different dominant personality characteristics compared with other individuals by evaluating the five dimensions of the Mini-IPIP scale among exercise addicts, regular exercisers, and exercise avoiders. The between-group differences of the results for the five dimensions are shown in Table 1. The results revealed a significant effect of group on the extraversion ($F_{2,\ 46} = 4.174$, $P = 0.022$, $\eta_p^2 = 0.154$) and neuroticism ($F_{2,\ 46} = 4.530$, $P = 0.016$, $\eta_p^2 = 0.165$) dimensions. In the extraversion dimension, least significant difference *post hoc* tests (Tukey HSD) revealed that regular exercisers (13.89) had higher extraversion scores than exercise addicts (11.47). In the neuroticism dimension, *post hoc* tests (Tukey HSD) showed that exercise addicts (13.13) scored higher than regular exercisers (10.39) and exercise avoiders (10.56). No group differences were observed in the agreeableness, conscientiousness, or openness dimension. Taken together, these results suggest that exercise addicts had higher scores for neuroticism compared with the other two groups and scored lower on extraversion compared with regular exercisers.

Classic Go/No-Go Task

We conducted a classic go/no-go task to observe differences in inhibition between the three groups. The behavioral and electrophysiological results were analyzed.

No difference in behavioral results. Only the RT of correct responses was analyzed. No significant between-group differences were identified in the mean RT of the go task (go RT) and the response accuracy of the go and no-go tasks (go ACC and no-go ACC) (Table 1).

Exercise addicts and exercise avoiders exhibited larger N2 amplitudes. A main effect of task on N2 amplitude ($F_{1,\ 44} = 44.894$, $P < 0.001$, $\eta_p^2 = 0.505$) was found as indicated by a larger N2 amplitude during the no-go task (−3.693 μV) compared with that during the go task (−1.519 μV). A main effect of group ($F_{2,\ 44} = 3.642$, $P = 0.035$, $\eta_p^2 = 0.141$) was identified as indicated by a larger N2 amplitude for exercise addicts (−3.027 μV) and exercise avoiders (−3.036 μV) than that for regular exercisers (−1.445 μV). No differences were observed between exercise addicts and exercise avoiders. No significant task–group interaction on N2 amplitude was found. The topographic scalp distribution and the grand average waveforms of the N2 and P3 amplitudes are shown in Figure 1.

The analysis revealed a main effect of task on P3 amplitude ($F_{1,\ 44} = 68.972$, $P < 0.001$, $\eta^2 = 0.611$), with the no-go task (6.483 μV) resulting in larger amplitudes compared with the go task (3.434 μV). No significant main effect of group or significant task–group interaction on P3 amplitude was observed. No significant main effect of group or significant task–group interaction on N2d and P3d amplitudes was found. Furthermore, no main effect of group on Go-N1 and Go-P2 amplitudes and no significant interaction were observed. No significant correlation between ERP (Go-N1 and Go-P2) and no-go ACC was found.

Taken together, no differences in behavioral performance within the classic go/no-go task were identified, but differences were found in electrophysiological data. The results for N2 amplitude suggested that exercise addicts and exercise avoiders required more cognitive resources to achieve the same effect on behavior.

Exercise-Related Go/No-Go Task Performance

To observe the reactions of exercise addicts under the reward condition, we designed an exercise-related go/no-go task. In this task, we could observe the performances of the three groups under a more realistic environment.

Higher no-go ACC was observed in regular exercisers. No significant between-group differences were found in go RT or go ACC (Table 1); however, a significant between-group difference was observed for the no-go ACC ($F_{2,\ 46} = 6.500$, $P = 0.003$, $\eta_p^2 = 0.220$). *Post hoc* tests (Tukey HSD) indicated a

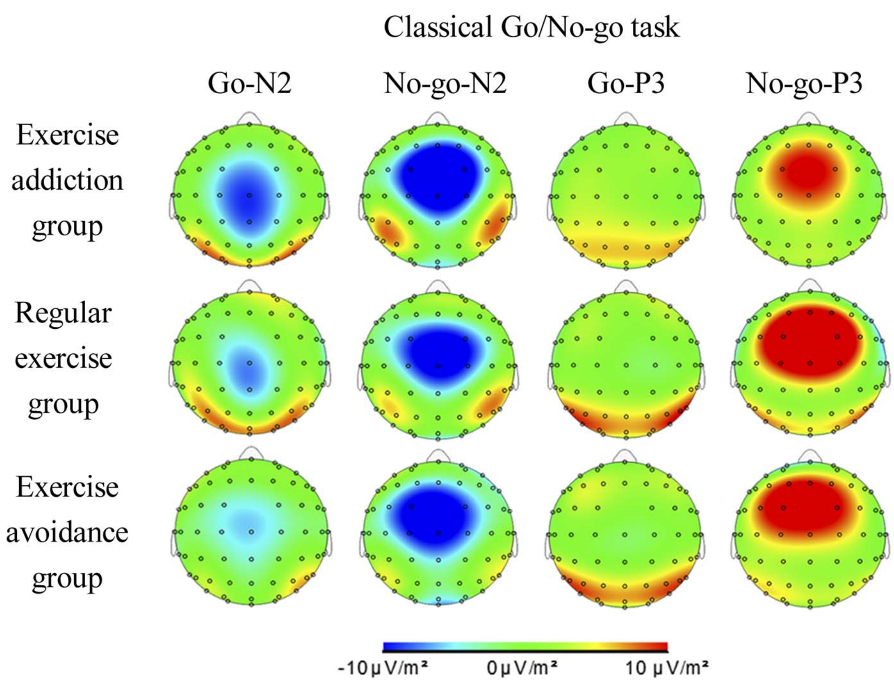

FIGURE 1—Topographic scalp distribution of N2 (spectrum scale: green to blue) and P3 (spectrum scale: green to red) amplitudes as a function of group and task (go/no-go) during the classic go/no-go task.

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higher no-go ACC in regular exercisers (0.95) compared with that in exercise addicts (0.88) and exercise avoiders (0.9), whereas no difference was found between exercise addicts and exercise avoiders.

Larger N1 and P2 amplitudes were observed in exercisers (exercise addicts and regular exercisers). Analyses of the Go-N1 amplitudes revealed a significant interaction of group–site ($F_{6,\ 135}$ = 2.947, P = 0.038, η_p^2 = 0.116). *Post hoc* tests (Tukey HSD) revealed larger Go-N1 amplitudes in the exercise addicts and regular exercisers compared with those in the exercise avoiders at the Fz, Pz, and Cz sites, whereas no difference was found between the exercise addiction and the regular exercise groups. In addition, a significant interaction effect of group–site on the Go-P2 amplitude was identified ($F_{6,\ 135}$ = 3.648, P = 0.013, η_p^2 = 0.390). *Post hoc* (Tukey HSD) tests revealed larger Go-P2 amplitudes in exercise addicts and regular exercisers compared with those in exercise avoiders at the Fz and Cz sites, but no difference was found between exercise addicts and regular exercisers. The topographic scalp distribution and the grand average waveforms of the Go-N1and Go-P2 amplitudes are shown in Figures 2 and 3. The Pearson correlation results showed that the N1 amplitudes on Fz, Cz, and Pz and the P2 amplitudes on Fz were significantly correlated with no-go ACC (see Table 1).

Larger N2 and P3d amplitudes were observed in exercise addicts. The results revealed a main effect of task on N2 amplitude ($F_{6,\ 45}$ = 28.812, P < 0.001, η_p^2 = 0.390). Larger N2 amplitudes were observed during the no-go task (−7.118 μV) compared with those during the go task (−5.582 μV). No significant main effect of group was observed; however, a significant group–site interaction was identified ($F_{10,\ 225}$ = 2.682, P = 0.042, η_p^2 = 0.106). *Post hoc* (Tukey HSD) results indicated that exercise addicts (−9.423 μV) exhibited larger N2 amplitudes compared with regular exercisers (−6.047 μV) on FPz (see Figure 3). The exercise addicts and the regular exercisers showed no significant difference compared with the exercise avoiders (−7.454 μV). No significant task–group interaction was observed ($F_{2,\ 45}$ = 2.241, P = 0.118, η_p^2 = 0.091).

A main effect of task on P3 amplitude was found ($F_{1,\ 45}$ = 17.181, P < 0.001, η_p^2 = 0.361), with the no-go task (5.401 μV) resulting in larger P3 amplitudes compared with the go task (4.055 μV) (see Figure 4). No significant main effect of group or significant task–group interaction was found. No significant main effect of group or group–site interaction on N2d amplitude was observed. However, a significant group–site interaction effect ($F_{10,\ 225}$ = 3.878, P = 0.009, η_p^2 = 0.147) on the P3d amplitude was found. *Post hoc* tests (Tukey HSD) revealed larger P3d amplitudes in the exercise addicts compared with those in the exercise avoiders at the FP1 and FPz sites (see Figure 5). No difference was found between the exercise addicts and the regular exercisers or between the exercise avoiders and the regular exercisers.

In summary, the results for Go-N1 and Go-P2 suggested that exercise-related stimuli triggered more activation among exercise addicts and regular exercisers. In addition, the larger N2 and P3d amplitudes and the lower no-go ACC of exercise addicts indicated that exercise addicts exhibited poor inhibition.

DISCUSSION

This study examined the personality traits of exercise addicts, regular exercisers, and exercise avoiders using the Mini-IPIP scale and examined the neurophysiological and behavioral correlates of impulsivity (including reward activity and inhibition) elicited by classic and modified go/no-go tasks in these groups.

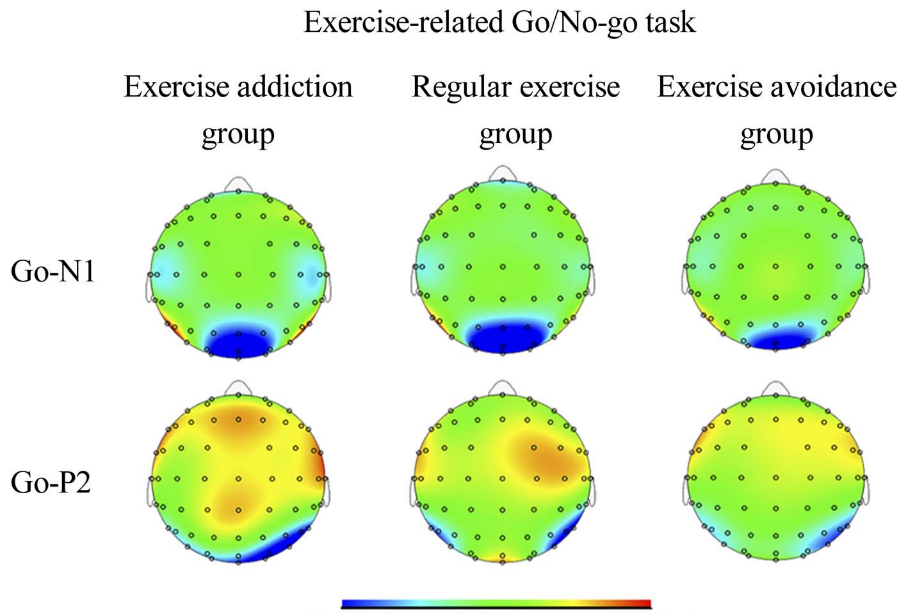

FIGURE 2—Topographic scalp distribution of Go-N1 (spectrum scale: green to blue) and Go-P2 (spectrum scale: green to red) amplitudes as a function of group during the exercise-related go/no-go task.

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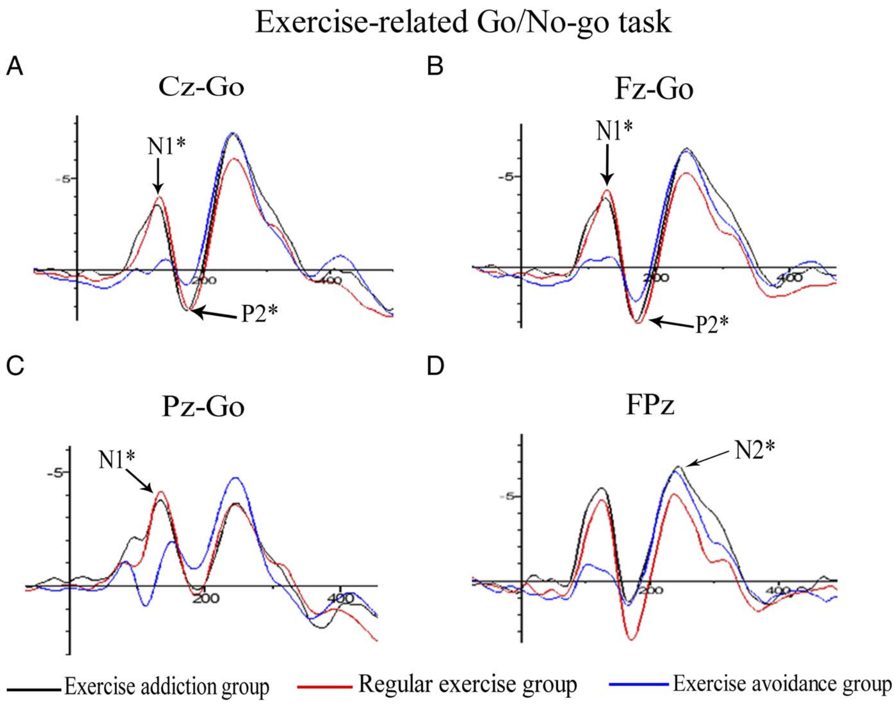

FIGURE 3—The grand average waveforms during the exercise-related task as a function of group. The grand average waveforms of N1 and P2 amplitudes for the go trials are presented at the Cz (A), Fz (B), and Pz (C) electrodes. The grand average waveforms of the N2 amplitudes for the go combined with the no-go trials are presented at the FPz (D) electrode. Colored lines represent the waveforms as a function of group. *Significant between-group differences at $P < 0.05$.

Our results suggested that the neuroticism personality trait, the brain reward features, and the inhibition system were associated with impulsivity among exercise addicts.

Our finding that exercise addicts had higher neuroticism scores compared with the other two groups is consistent with results from previous studies. These results are similar to those presented by Lichtenstein et al. (33) who found positive associations between neuroticism and exercise addiction. Another study also found that exercise addicts scored higher for neuroticism compared with the control group (34), revealing that exercise addicts exhibited the neuroticism personality trait, which reflects the ability to regulate emotions and is related to impulsivity (7).

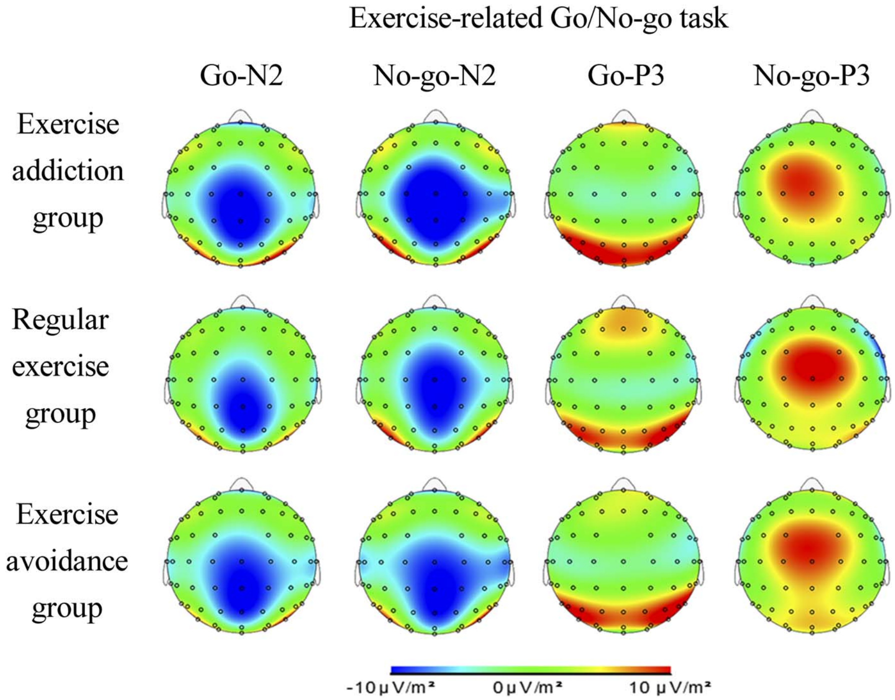

FIGURE 4—Topographic scalp distribution of N2 (spectrum scale: green to blue) and P3 (spectrum scale: green to red) amplitudes as a function of group and task (go/no-go) during the exercise-related go/no-go task.

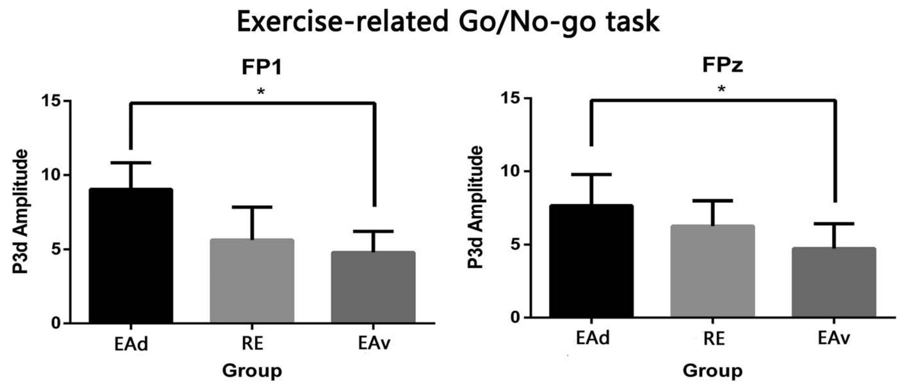

FIGURE 5—Group differences in P3d (the differences in P3 amplitudes between go and no-go stimuli, no-go minus go) in the exercise-related go/no-go task. *P < 0.05. EAd, exercise addiction group; RE, regular exercise group; EAv, exercise avoidance group.

Interestingly, our result that exercise addicts scored lower for extraversion compared with regular exercisers has not been previously reported. A study by Courneya and Hellsten (35) found a positive relationship between exercise behavior and extraversion in healthy exercisers. Vollrath and Torgersen (36) suggested that unhealthy behaviors are probably more frequent among individuals with combinations of negative personality traits (e.g., high neuroticism, low extraversion, and low agreeableness). Consistent with previous research, exercise behaviors may explain the higher levels of extroversion observed in the regular exercisers in the present study. By contrast, a positive relationship between exercise addiction and extraversion has been reported in some studies (37).

According to the results, overactivation of the reward system was evident among exercisers during the exercise-related task. In the exercise-related go/no-go task, exercise-related pictures were selected as the go stimuli, which may serve as a reward stimulus for addicts (38). The results indicated that exercisers (addicted and nonaddicted) had larger N1 and P2 amplitudes during the go task in the exercise-related go/no-go task compared with exercise avoiders. A larger N1 amplitude is thought to reflect enhanced attention toward the stimulus, and a larger P2 amplitude has been observed among exercisers in response to addict-related cues (13). Therefore, the higher N1 and P2 amplitudes in the exercise addiction and regular exercise groups may indicate overactivation of the reward system as reflected by an automatic attention bias to reward stimuli, followed by deep processing related to the reward.

Overactivation of the reward system may be a result of long-term exposure to exercise. In the present study, exercise addicts and regular exercisers were the "exercisers" relative to exercise avoiders. The larger N1 and P2 amplitudes of the two exercise groups compared with those of the exercise avoiders may indicate that increased sensitivity to exercise-related stimuli was modified by exposure to exercise. This finding is similar to research on smokers (addicted and nonaddicted) and nonsmokers conducted by Fehr et al. (39), which showed larger N1 amplitudes for verbal smoking-related stimuli and indicated that smokers were affected by smoking-related stimuli during the very early stages of information processing. Accordingly, sensitivity to exercise-related stimuli among exercise addicts is indicative of overactivation of the reward system, which supports our first hypothesis. Moreover, the same results were observed in regular exercisers as well as exercise addicts, which supports our second hypothesis that exposure to exercise is related to increased appetence for exercise-related stimuli through alteration of the brain reward system.

The results suggested that exercise addicts exhibited an impaired inhibition capacity. In the classic go/no-go task, exercise addicts did not show greater decrements in behavioral performance (RT and ACC) relative to nonaddicts (regular exercisers and exercise avoiders), in contrast to previous findings from studies on addiction (31). Nevertheless, differences in the N2 component were identified. Exercise addicts and exercise avoiders showed larger N2 amplitudes compared with regular exercisers. In correctly performed trials, greater N2 and P3 amplitudes were associated with weaker inhibitory control (17). According to previous research, the N2 component reflects an early subprocess of response inhibition, namely, conflict detection, and P3 is related to motor inhibition (15). Therefore, the present findings suggest that exercise addicts and exercise avoiders had lower inhibition abilities compared with regular exercisers, and poor inhibition was mainly related to conflict detection. The previous studies paid attention to the differences between Internet addicts and nonaddicts and found that the addicts showed lower inhibition than the nonaddicts (14,15). In the present study, the nonaddicts were divided into regular exercisers and exercise avoiders. Results showed a higher inhibition of regular exercise group, but no difference of N2 and P3 was observed between exercise addict group and exercise avoidance group. There was evidence that healthy regular exercise could improve cognitive inhibition (40). On the one hand, our findings confirmed this result and, on the other hand, revealed that exercise addicts and exercise avoiders did not show difference in the simple classic go/no-go task. Therefore, it might be that the grouping led to different results, which indicated that it would be necessary to compare the results of the different grouping in future research.

In the exercise-related go/no-go task, a group difference in no-go ACC was found. Exercise addicts and exercise avoiders more frequently failed to inhibit their proponent motor response to no-go trials compared with regular exercisers. Moreover, based on the group–electrode interaction, exercise addicts had larger N2 amplitudes than regular exercisers at FPz and larger P3d amplitudes than exercise avoiders on FPz and FP1. These results suggest that exercise addicts recruited more cognitive control resources when they had to detect conflict and inhibit their responses in the exercise-related go/no-go task. In other words, exercise addicts showed reduced conflict detection compared with regular exercisers and impaired motor inhibition compared with exercise avoiders.

In summary, these findings partially supported the first hypothesis and indicated that the reward and inhibition systems of exercise addicts were abnormal. Different results for the classic and exercise-relate go/no-go tasks may indicate that reward stimuli moderated impulse control capacity. Combined with the significant correlations between ERP and behavior in the exercise-related task, we propose that the cognitive bias toward exercise-related stimuli may relate to a loss of control. However, the specific relationship needs further study. In addition, overactivation of the reward system was observed in all exercisers, but the lowest capacity for impulse inhibition was observed in exercise addicts, which may suggest that a damaged inhibition system was a unique factor in exercise addiction. However, the present study is a cross-sectional study, which is not sufficient for determining a causal conclusion. Therefore, future longitudinal research should be performed to clarify the relationship between exercise addiction and inhibition.

In conclusion, exercise addicts showed a higher neuroticism personality trait and exhibited an impaired reward system, which may be related to exposure to exercise, and an impaired inhibition system. On the behavior tasks, exercise addicts made more errors under the effect of reward stimuli (exercise-related pictures). These results reflect the impulsivity associated with exercise addiction and affirmed the deficiencies of the two brain systems associated with loss of control, which was important for developing exercise addiction. In addition, a future study on exercise addiction may focus on the inhibition system.

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