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ARTICLE

Environmental Modulation of Flow, Mood States, and Brain Waves during Moderate-Intensity Cycling

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ABSTRACT: Objectives: The present study aimed to investigate how environmental context modulates flow experience, mood states, and brain waves during moderate-intensity cycling. **Methods:** Fifty healthy adults were initially recruited; four participants withdrew during the study, resulting in a final sample of 46 participants. Flow experience was assessed using the Flow State Scale (FSS), mood states were measured using the Profile of Mood States (POMS), and cortical activity was recorded using a Quick-20 Dry EEG headset. Participants performed 300 s of moderate-intensity cycling under three environmental conditions: indoor, outdoor, and virtual reality (VR). Repeated-measures analysis of variance (ANOVA) was conducted, and Bonferroni-adjusted post hoc tests were applied. **Results:** Significant environmental differences were observed for Concentration on Task at Hand, Action–Awareness Merging, Loss of Self-Consciousness, Sense of Control, Autotelic Experience, and total FSS score (all $p < 0.001$), whereas Transformation of Time was not significant. Flow experience was significantly higher in the outdoor and VR conditions compared with the indoor condition. All POMS subscales (Tension–Anxiety, Depression–Dejection, Anger–Hostility, Vigor–Activity, Fatigue–Inertia, and Confusion–Bewilderment) and the Total Mood Disturbance Score (TMDS) differed significantly across environments (all $p < 0.001$), indicating more favorable mood states in outdoor and VR conditions relative to indoor cycling. For electroencephalographic (EEG) activity, significant environmental effects were found in theta, alpha, and gamma bands ($p < 0.001$), but not in beta activity. Theta power was greatest in the outdoor condition. Alpha power followed the order outdoor > indoor > VR. Gamma power was highest in the VR condition, followed by indoor and outdoor conditions. **Conclusions:** These findings indicate that exercise environment significantly influences psychological immersion, affective states, and neural activation during cycling. The results provide empirical evidence supporting the development of environment-based exercise guidelines and mental health–oriented training and rehabilitation programs.

KEYWORDS: Cycling; environment; flow; mood states; brain waves; virtual reality; electroencephalogram

1 Introduction

Cycling is traditionally performed outdoors; however, depending on situational constraints and exercise objectives, it is increasingly conducted indoors or within virtual reality (VR) environments. Adverse weather conditions, air pollution such as fine particulate matter, and public health crises, including SARS and COVID-19, have limited access to outdoor and shared indoor facilities. Furthermore, in rehabilitation contexts, patients frequently utilize stationary ergometers indoors to ensure safety. More recently, VR technology has been employed to provide ecologically controlled, repeatable, and engaging exercise environments.

Despite the increasing diversity of cycling environments, limited empirical research has systematically examined how environmental context influences psychological immersion, affective responses, and neural activation during exercise. Understanding these environmental effects is particularly relevant within mental health promotion, where exercise is often prescribed not only for physiological benefits but also for emotional regulation and cognitive enhancement. Therefore, this study compared flow experience, mood states, and EEG activity during cycling performed in indoor, outdoor, and immersive VR environments.

Cycling was originally developed as a means of transportation; however, it now serves as an important modality for promoting physical, psychological, and mental health [1,2]. As a representative form of aerobic exercise, moderate-intensity cycling enhances cortical activation, cerebral hemodynamics, and metabolic processes, thereby fostering a neurobiological environment conducive to cognitive enhancement [3–5]. Aerobic exercise has been shown to improve cognitive performance, delay memory decline, promote hippocampal neurogenesis, increase neurotransmitter availability, stimulate brain-derived neurotrophic factor (BDNF), and increase brain volume [6,7]. Moreover, moderate-to-high-intensity cycling exercise enhances cognitive function and activates cortical regions associated with executive processing [8,9].

Flow is defined as a subjective psychological state characterized by complete immersion in an activity, accompanied by intense concentration, intrinsic motivation, and diminished self-awareness [10]. It represents a state in which enjoyment and challenge are optimally balanced [11]. Individuals in a flow state become fully absorbed in the task and are intrinsically motivated to sustain engagement [12]. Consequently, exercise-related flow may serve as a foundational mechanism for long-term exercise adherence [13]. From the perspective of ecological dynamics theory, behavior emerges through self-organization within the performer–environment system [14]. Flow experiences reflect both the performer's capabilities and the affordances of the physical environment [15]. Thus, it can be inferred that the exercise environment plays a critical role in shaping flow experiences. Mood refers to transient affective states accompanied by physiological changes and encompassing a continuum from highly positive to highly negative emotions [16]. Mood states fluctuate in response to situational, environmental, and internal cues [17]. Therefore, assessing mood states provides an effective means of comparing environmental influences during cycling. A substantial body of research suggests that exposure to natural environments promotes mental health [18–20]. Real nature exposure appears to provide greater well-being benefits than indirect experiences [21]. However, much of the evidence supporting nature's therapeutic potential derives from digital simulations [22]. Accordingly, direct comparative analysis of actual and virtual exercise environments is warranted.

Electroencephalogram measures electrical potentials generated by neuronal activity at the scalp and is widely used to assess real-time brain function. EEG signals reflect the summation of excitatory postsynaptic potentials arising from metabolic processes, neurotransmitter release, and ion exchange in neuronal populations [23]. Electroencephalogram offers advantages including non-invasiveness, high temporal resolution, cost-effectiveness, and portability, allowing real-time measurement during exercise [24–26]. Prior research has demonstrated environmental differences in cortical activation during walking tasks [27], suggesting that the exercise environment may influence neural activation patterns.

Accordingly, the present study aimed to compare the effects of indoor, outdoor, and VR cycling environments on flow experience, mood states, and EEG activity. Differences across environments may inform the development of exercise-learning strategies and mental health–oriented exercise and rehabilitation programs.

2 Methods

2.1 Participants

To determine the required sample size for this study, G*Power 3.1 software was used. Assuming a repeated-measures analysis of variance (ANOVA) with power ($1 - \beta$ error probability) = 0.95, α error probability = 0.05, effect size $f = 0.25$, one group, and three measurements, the minimum required sample size was calculated to be 43 participants. Fifty healthy adults capable of physical activity were recruited who had no cardiovascular, musculoskeletal, or metabolic diseases. Four participants withdrew during the study, resulting in data from 46 participants being included in the final analysis. The characteristics of the participants are presented in Table 1. This study was approved by the Research Ethics Committee of Seoul National University of Science and Technology (IRB No. 2023-0023-01). Written informed consent to participate in this study was provided by the participants.

Table 1: Characteristics of the study participants.

Participants (Male/Female)	Age (years), Mean ± SD	Height (cm), Mean ± SD	Weight (kg), Mean ± SD
46 (38/8)	21.70 ± 2.37	172.33 ± 8.93	71.63 ± 11.73

2.2 Measures

2.2.1 Flow State Scale

The Flow State Scale (FSS) [28] was modified for bicycle riders and applied to assess the degree of flow experience [29]. The instrument consists of 24 items across six factors: Concentration on Task at Hand (4 items), Action–Awareness Merging (4 items), Transformation of Time (4 items), Loss of Self-Consciousness (4 items), Sense of Control (4 items), and Autotelic Experience (4 items). The Cronbach's α values for each factor are as follows: Concentration on Task at Hand (0.865), Action Awareness Merging (0.832), Transformation of Time (0.805), Loss of Self-Consciousness (0.897), Sense of Control (0.894), and Autotelic Experience (0.869). Responses are recorded on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Higher scores indicate a greater degree of flow experience.

2.2.2 Profile of Mood States

The Korean version of the Profile of Mood States (K-POMS) [30], adapted from the original POMS [31], was used to measure changes in mood states. The instrument consists of 65 items derived from factor analysis and includes the following subscales: Tension–Anxiety (TA) (9 items), Depression–Dejection (DD) (15 items), Anger–Hostility (AH) (12 items), Vigor–Activity (VA) (8 items), Fatigue–Inertia (FI) (7 items), Confusion–Bewilderment (CB) (7 items), and Positive Emotion (7 items). The Cronbach's α values for each factor are as follows: TA (0.78), DD (0.90), AH (0.90), VA (0.90), FI (0.78), and CB (0.67). Responses are rated on a 5-point Likert scale ranging from 0 (absent) to 4 (very much). Among the six primary POMS factors, Vigor–Activity represents a positive mood state and was therefore reverse-coded (TMD = (AH + CB + DD + FI + TA) − VA) [32]. Consequently, higher total scores indicate more negative mood states.

2.2.3 EEG

EEG activity was recorded using the Quick-20 Dry EEG headset (Cognionics, San Diego, CA, USA). This device is a non-invasive, dry, mobile EEG system in a headset format. Electrodes were positioned according to the international 10–20 system at eight scalp sites: prefrontal (Fp1, Fp2), frontal (F3, F4), parietal (P3, P4), and occipital (O1, O2). The sampling rate was set at 500 Hz, and a bandpass filter ranging from 0.5 Hz to 50 Hz was applied during data acquisition.

2.3 Task and Procedures

The purpose of this study was to compare the effects of different exercise environments during cycling on flow experience, mood states, and EEG activation. EEG was measured during moderate-intensity exercise (64–76% HRmax), while FSS and POMS were administered after exercise completion. Exercise environments were defined as indoor, outdoor, and VR conditions. Exercise intensity was determined based on the guidelines of the American College of Sports Medicine [33]. Aerobic exercise intensity was calculated using the Karvonen formula [34].

$$\text{HR} = 220 - \text{age}$$

$$\text{Target HR} = [(\text{HRmax} - \text{Resting HR}) \times \%\text{Intensity}] + \text{Resting HR}$$

Prior to participation, all volunteers received detailed oral and written explanations regarding the purpose of the study, experimental tasks, procedures, precautions, and issues related to personal information. Only those who fully understood the study and provided written informed consent were included. The Physical Activity Readiness Questionnaire (PAR-Q) was administered to ensure that participants had no health-related contraindications.

Each participant completed three experimental sessions—one in each environment. Each session lasted approximately 40 min. Considering participant fatigue, a 4~5-day interval was set between measurements, and a counter-balance design was applied to prevent the order effect resulting from repeated measurements. In the first experiment, all participants were measured in an indoor condition, while 23 participants were measured in a VR condition in the second experiment and in an outdoor condition in the third experiment. The remaining 23 participants were measured in an outdoor condition in the second experiment and in a VR condition in the third experiment.

After completing sufficient warm-up exercises, participants wore a Polar H10 heart rate monitor (Polar Electro Oy, Kempele, Finland) and the Quick-20 Dry EEG headset.

- In the indoor condition, participants performed cycling on a stationary bicycle.
- In the outdoor condition, participants cycled on a designated bicycle-only road.
- In the VR condition, participants wore an Oculus Meta Quest 3 headset (Meta Platforms, Menlo Park, CA, USA) connected to a computer running the Zwift application version 1.73 (Zwift Inc., Long Beach, CA, USA). Participants cycled on a free-riding course within the Zwift virtual environment while using the same stationary bicycle setup as in the indoor condition.

In all environments, participants gradually increased cycling speed until reaching their target heart rate. Once the target heart rate was achieved, participants maintained that intensity for 300 s. After the EEG recording was completed, participants dismounted the bicycle, rested, and then completed the FSS and POMS questionnaires.

2.4 EEG Analysis

In this study, BioScan version 6.14 software developed by Bio-tech (Daejeon, Republic of Korea) was used for the real-time monitoring, storage, and analysis of brainwave data. BioScan software is capable of data analysis, editing, and the removal of noise and electrical artifacts. This software calculates the average value for each band. EEG frequency bands were classified as follows: theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), and gamma (30–50 Hz). From the total 300 s of collected EEG data, the first and last 60 s were removed. Bandpass and notch filters were applied to eliminate specific noise and electrical artifacts. To reduce individual differences related to scalp thickness, skull thickness, electrode–skin contact, and tension during measurement, EEG data were analyzed using relative power spectrum values for each channel (Relative Power Spectrum = Absolute Power Spectrum at that Frequency/Total Power Spectrum).

2.5 Data Analysis

The independent variable was exercise environment (indoor, outdoor, VR), and the dependent variables were FSS subscales, POMS subscales, and EEG frequency bands. Repeated-measures ANOVA was conducted. Bonferroni corrections were applied for post hoc comparisons. When Mauchly's test of sphericity was violated, the Greenhouse–Geisser correction was applied if epsilon was less than 0.75, and the Huynh–Feldt correction was applied if epsilon exceeded 0.75. All statistical analyses were conducted using SPSS version 28 (IBM Corp., Armonk, NY, USA). The level of statistical significance was set at $p < 0.05$.

3 Results

3.1 Flow States

The comparison of flow experience across exercise environments during cycling is presented in Table 2. Significant differences according to exercise environment were found for Concentration on Task at Hand [F(1.794, 80.713) = 77.267, $p < 0.001$, $\eta_p^2 = 0.632$], Action–Awareness Merging [F(2, 90) = 24.729, $p < 0.001$, $\eta_p^2 = 0.355$], Loss of Self-Consciousness [F(2, 90) = 10.986, $p < 0.001$, $\eta_p^2 = 0.196$], Sense of Control [F(1.626, 73.160) = 42.586, $p < 0.001$, $\eta_p^2 = 0.486$], Autotelic Experience [F(2, 90) = 65.544, $p < 0.001$, $\eta_p^2 = 0.593$], and total score [F(1.651, 74.294) = 57.605, $p < 0.001$, $\eta_p^2 = 0.561$]. Post hoc analyses indicated significant differences between the indoor and outdoor conditions, and between the indoor and VR conditions, for all of the above factors. However, no significant difference was found for Transformation of Time [F(2, 90) = 2.863, $p > 0.05$, $\eta_p^2 = 0.060$].

Table 2: Flow experience across exercise environments during cycling.

Factors	Indoor Environment, Mean ± SD	Outdoor Environment, Mean ± SD	VR Environment, Mean ± SD	F	p	η_p^2
Concentration on Task at Hand	2.788 ± 0.910	4.141 ± 0.588	4.348 ± 0.616	77.267	<0.001	0.632
Action-Awareness Merging	3.038 ± 0.952	3.962 ± 0.782	3.880 ± 0.732	24.729	<0.001	0.355
Transformation of Time	3.179 ± 0.929	3.402 ± 0.783	3.533 ± 0.833	2.863	0.062	0.060
Loss of Self-Consciousness	3.321 ± 1.031	3.848 ± 0.781	4.168 ± 0.888	10.986	<0.001	0.196
Sense of Control	2.804 ± 0.962	4.000 ± 0.860	4.000 ± 0.791	42.586	<0.001	0.486
Autotelic Experience	2.571 ± 1.032	4.125 ± 0.707	4.022 ± 0.789	65.544	<0.001	0.593
Total Score	2.950 ± 0.692	3.913 ± 0.449	3.992 ± 0.511	57.605	<0.001	0.561

3.2 Mood States

The comparison of mood state changes across exercise environments during cycling is presented in Table 3. Significant differences according to exercise environment were found for Tension–Anxiety [F(1.837, 82.686) = 14.780, $p < 0.001$, $\eta_p^2 = 0.247$], Depression–Dejection [F(1.595, 71.768) = 24.921, $p < 0.001$, $\eta_p^2 = 0.356$], Anger–Hostility [F(1.677, 75.455) = 25.616, $p < 0.001$, $\eta_p^2 = 0.363$], Vigor–Activity [F(2, 90) = 39.574, $p < 0.001$, $\eta_p^2 = 0.468$], Fatigue–Inertia [F(1.822, 82.011) = 28.382, $p < 0.001$, $\eta_p^2 = 0.387$], Confusion–Bewilderment [$F(1.725, 77.647) = 25.323$, $p < 0.001$, $\eta_p^2 = 0.360$], and Total Mood Disturbance Score (TMDS) [$F(1.709, 76.912) = 43.490$, $p < 0.001$, $\eta_p^2 = 0.491$]. Post hoc analyses revealed significant differences between the indoor and outdoor conditions and between the indoor and VR conditions for all factors.

Table 3: Mood states across exercise environments during cycling.

Factors	Indoor Environment, Mean ± SD	Outdoor Environment, Mean ± SD	VR Environment, Mean ± SD	F	p	η_p^2
Tension-Anxiety	1.389 ± 0.745	1.104 ± 0.506	0.973 ± 0.445	14.780	<0.001	0.247
Depression-Dejection	0.829 ± 0.787	0.320 ± 0.445	0.319 ± 0.417	24.921	<0.001	0.356
Anger-Hostility	0.969 ± 0.773	0.480 ± 0.487	0.422 ± 0.450	25.616	<0.001	0.363
Vigor-Activity (reverse coding)	2.160 ± 0.681	1.269 ± 0.620	1.370 ± 0.743	39.574	<0.001	0.468
Fatigue-Inertia	1.854 ± 0.909	1.168 ± 0.691	1.028 ± 0.590	28.382	<0.001	0.387
Confusion-Bewilderment	1.469 ± 0.828	0.860 ± 0.499	0.935 ± 0.421	25.323	<0.001	0.360
TMDS	1.445 ± 0.642	0.867 ± 0.416	0.841 ± 0.378	43.490	<0.001	0.491

Note: VR, virtual reality; TMDS, Total Mood Disturbance Score.

3.3 EEG

The comparison of EEG activation across exercise environments during cycling is presented in Table 4 and Fig. 1. Significant differences according to exercise environment were found for theta waves [$F(2, 90) = 79.439$, $p < 0.001$, $\eta_p^2 = 0.638$]. Post hoc analysis indicated significant differences between the indoor and outdoor conditions and between the outdoor and VR conditions. Significant differences were also found for alpha waves [$F(2, 90) = 80.267$, $p < 0.001$, $\eta_p^2 = 0.641$], with post hoc analyses revealing significant differences among all three conditions. Gamma waves showed significant environmental differences [$F(1.461, 65.756) = 47.218$, $p < 0.001$, $\eta_p^2 = 0.512$], and post hoc analyses indicated significant differences among all three conditions. However, no significant difference was observed for beta waves [$F(1.237, 55.649) = 1.213$, $p > 0.05$, $\eta_p^2 = 0.026$].

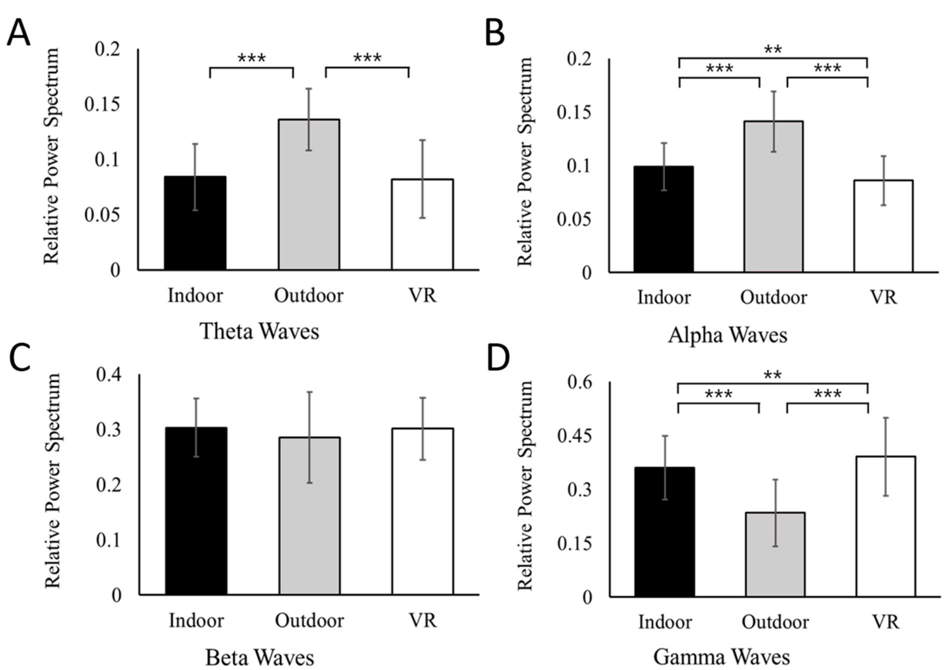

Figure 1: Electroencephalographic (EEG) activity across exercise environments during cycling. (**A**) Theta waves; (**B**) Alpha waves; (**C**) Beta waves; (**D**) Gamma waves. Statistical significance: $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 4: Electroencephalographic (EEG) activity across exercise environments during cycling.

Frequency	Indoor Environment, Mean ± SD	Outdoor Environment, Mean ± SD	VR Environment, Mean ± SD	*F*	*p*	η_p^2
Theta	0.084 ± 0.030	0.136 ± 0.028	0.082 ± 0.035	79.439	<0.001	0.638
Alpha	0.099 ± 0.022	0.141 ± 0.028	0.086 ± 0.023	80.267	<0.001	0.641
Beta	0.303 ± 0.053	0.285 ± 0.082	0.301 ± 0.056	1.213	0.287	0.026
Gamma	0.360 ± 0.089	0.235 ± 0.093	0.391 ± 0.108	47.218	<0.001	0.512

4 Discussion

Exercise environment may be as important as exercise itself [35,36], and it may vary depending on situational demands and exercise purposes. However, comparative research examining how exercise environments influence flow experience, mood states, and EEG activation remains limited. Therefore, this study compared the effects of indoor, outdoor, and VR cycling environments on psychological and neurophysiological outcomes.

Leisure activities such as sports and computer games have the potential to be highly rewarding, enjoyable, and motivating [37,38]. One of the most positive and rewarding mental states derived from such activities is flow [39]. Because flow is associated with functional characteristics such as concentration, motivation, and confidence, its relationship with performance is particularly compelling [40]. Flow maximizes innate human potential [41] and enhances performance, engagement, and task persistence [42]. Therefore, increasing flow experience in learning, training, and rehabilitation contexts is highly important.

Previous research comparing natural conditions, stationary bike exercise without visualizations, non-immersive virtual reality (nIVR), and immersive virtual reality (IVR) reported differences in flow experience, with the highest levels observed in IVR, followed by natural conditions, stationary bike without visualizations, and nIVR [43]. In the present study, flow experience also differed across environments, with outdoor and VR cycling producing higher levels than indoor cycling. The absence of differences in the Transformation of Time may be attributable to the short duration of cycling. Previous research indicates that discrepancies between average heart rate and rating of perceived exertion during endurance cycling emerge between 18 and 22 min [44], suggesting that sufficient duration may be necessary to induce deep immersive states.

Green exercise, which combines physical activity and nature exposure, is known to benefit physical and mental health [45], and VR exercise has been reported to produce positive physiological, psychological, and rehabilitative outcomes compared to indoor exercise [46]. In studies involving patients with type 2 diabetes, outdoor green cycling produced more positive mood states than indoor stationary cycling [47]. Similarly, VR cycling improved mood states compared to indoor cycling in patients with type 1 diabetes [48]. Research involving university students also demonstrated greater mood improvements following VR exercise compared to indoor aerobic exercise [49]. Consistent with these findings, the present study found more positive mood states in outdoor and VR conditions compared to indoor cycling.

Electroencephalogram enables direct and effective detection of emotional states based on brain activity [50] and has potential as a diagnostic adjunct in mental, cognitive, and neurological disorders [51]. EEG frequency bands are categorized into delta, theta, alpha, beta, and gamma bands [52]. Numerous studies have reported greater neural benefits from outdoor exercise compared to indoor exercise [36,53–56]. Outdoor exercise has been associated with lower perceived activation and increased frontal alpha activity, whereas VR exercise has been associated with greater beta activation compared to indoor exercise [27,57].

In the present study, outdoor cycling resulted in greater theta and alpha activation compared to indoor and VR conditions, whereas gamma activation was lower outdoors. No difference was found for beta activity. It is plausible to interpret that the observed peak in gamma power during the VR condition suggests a state of heightened cortical activation. While increased high-frequency activity can sometimes be associated with cognitive load, the concomitant increase in Flow scores and positive mood in our study suggests that this gamma activity reflects heightened cognitive engagement and multisensory integration.

In an immersive VR environment, the brain must integrate dynamic visual flow with proprioceptive feedback from cycling. Gamma oscillations are hypothesized to play a critical role in binding these disparate sensory streams into a unified perception of presence [58]. Furthermore, the immersive visual demands of VR may have triggered an externally-directed attentional focus, which is consistent with the increased gamma power observed in tasks requiring high levels of environmental interaction and sensory-motor coordination [59].

Physical activity in natural environments may reduce stress and anxiety and improve overall psychological well-being [60]. It has been hypothesized that enhanced enjoyment and relaxation during outdoor exercise may support long-term exercise adherence [61]. Numerous studies emphasize the positive effects of nature on cognition and mental health [62], and prior research has demonstrated that exercise in nature is perceived as more enjoyable than indoor exercise [63–65].

Consistent with this body of evidence, the present study demonstrated that outdoor exercise was more effective than indoor and VR exercise in enhancing flow experience, improving mood states, and promoting favorable EEG activation. However, when outdoor exercise is not feasible, VR exercise may serve as an alternative. From an ecological dynamics perspective, behavior emerges from self-organizing performer–environment interactions [14]. Therefore, advancements in VR technology that more accurately replicate real outdoor environments may yield effects comparable to those observed in natural settings.

As this is an experimental study, there are several limitations. First, the ratio of male to female participants was not appropriate. Therefore, it was not possible to analyze differences based on gender in this study. Second, because the experiment was conducted in the field as well as in the laboratory, it was not possible to provide the same environment or ensure perfect control for all participants. Therefore, it is believed that if these limitations are addressed in future research, more accurate measurements can be taken, thereby further enhancing the quality of the study. Third, unlike traditional laboratory-based studies that utilize isolated cognitive stimuli, this study focused on the complex environmental modulation of the exercise experience. Future research should aim to bridge this gap by employing higher-density EEG to better isolate these specific functional components within diverse physical environments.

5 Conclusions

This study examined the effects of environmental differences during cycling on flow experience, mood states, and EEG activity. Compared with indoor cycling, outdoor and VR cycling produced higher levels of flow experience and more positive mood states. Outdoor cycling demonstrated the most favorable EEG activation patterns. Exercise environments may vary depending on situational constraints and purposes. The findings of this study contribute to understanding how the exercise environment influences psychological immersion, affective responses, and neural activation. These results may serve as foundational evidence for developing exercise environment guidelines and designing exercise and rehabilitation programs aimed at promoting mental health.

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Availability of Data and Materials: The raw data supporting the conclusions of this article will be made available by the author, without undue reservation.

Ethics Approval: The studies involving human participants were reviewed and approved by the Research Ethics Committee of Seoul National University of Science and Technology (IRB No. 2023-0023-01). Written informed consent to participate in this study was provided by the participants.

Conflicts of Interest: The authors declare no conflicts of interest.

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