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Research article

The Restorative Effects of Nature Exposure on The Self-Regulation Resources in Mentally Fatigued Soccer Players: A Randomized Controlled Trial

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Abstract

Interventions involving exposure to nature can increase self-regulatory resources. However, this improvement has never been examined in mentally fatigued soccer players who have insufficient resources to self-regulate and maintain specific performances. The present study aims to investigate how exposure to nature influences the self-regulation capability of university soccer players who are mentally fatigued. The participants aged 18-24 years (M = 20.73 ± 2.00), with an average training duration of 5.14 ± 1.31 years, were randomly divided into six different groups (three experimental groups and three control groups). Each experimental group was compared with its corresponding control group using three different intervention durations: 4.17 min, 8.33 min, and 12.50 min. A forty-five-minute Stroop task was used to induce mental fatigue, followed by the intervention. The indicators of self-regulation, both physiological (heart rate variability, or HRV) and psychological (competitive state anxiety), were recorded. Experimental Group 3 (12.50 min intervention) only showed significant improvement in HRV ($p = 0.008$, $d = 0.93$), competitive state anxiety (cognitive and somatic anxiety $p = 0.019$, $d = 0.86$; state confidence $p = 0.041$, $d = 0.797$) compared to control group 3. Nature exposure significantly improves self-regulation in mentally fatigued soccer players. Specifically, the 12.50 min intervention showed the greatest improvements in both HRV and competitive state anxiety, suggesting that a longer duration of nature exposure enhances mental restoration more effectively.

Key words: mental fatigue; soccer players; restortation; nature

Introduction

In the context of athletic performance, self-regulation refers to the ability to adaptively adjust physiological and psychological states to fit specific situations, such as in soccer (Baumeister and Vohs, 2016; Nigg, 2017). In soccer, players must exert self-regulation and adjust impulses: for example, downregulate their anxiety in the high-pressure competition to chill out and more concentrated on the original task needed (e.g., passing decision-making) (Fortes et al., 2021c; Gantois et al., 2019; Sun et al., 2022a). On the other hand, self-regulation is not always successful. One illustration of lapses in this ability is given by the self-regulation strength model (Baumeister and Heatherton, 1996; Sun et al., 2022b), which shows many of an individual's "self" activities depend on the same resource pool, just as strength or energy. When the resources are depleted, the sports performance will be impaired (Englert, 2016; Hagger et al., 2010).

The strength model of self-regulation considers every act of self-regulation, voluntary attention, as well as the decision to share one resource pool, and that prolonged actions thus lead to a state of fatigue (Inzlicht and Berkman, 2015). For example, a soccer player continually making strategic decisions and maintaining sustained attention during a game is using up the self-regulation resources with exerting "self" executive function, which can eventually result in mental fatigue (Englert, 2016).

Mental fatigue (MF) has been attractive in the sports field in recent years. It is generally a psychobiological condition that is caused by increased demand cognitive actions (Hancock and Desmond, 2001), which cause acute tired feelings and influence many subsequent performances. Mounting evidence has shown that MF has an adverse effect on soccer performance (Filipas et al., 2021; Fortes et al., 2020; Smith et al., 2017; 2015; Sun et al., 2022c; 2021). The latest longitudinal studies further demonstrated the increase of MF throughout the competition season ecologically (Díaz-García et al., 2023; Ferreira et al., 2024).

One "self" function related to the cognitive activity of directed attention seems to be inevitably needed to maintain performances in soccer (Smith et al., 2018). This involving ignoring irrelevant stimuli such as worrisome thoughts and state anxiety, while concentrating on the action-relevant task at hand (the position of teammates or ball location). Importantly, the implementation of directed attention requires self-regulation (Englert, 2017), because it is voluntary and effortful (Yantis, 2009). When resources of self-regulation are depleted, the players' attention becomes automatically occupied by any threatening stimulus that can either be from an external source (e.g., clutter) or from an internal source (e.g., worrisome thoughts or competitive anxiety), which results in less available attention for the actual task and soccer performance (Badin et al., 2016; Fortes et al., 2020; Gantois et al., 2019; Smith et al., 2016b; Sun et al., 2022c).

Additionally, self-regulation takes place through the interaction of specific structures of the brain, including parts of the frontal cortex, interacting with the brain's cen-

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tral autonomic network (Di Bello et al., 2024; Thayer, 2009). Cortical awareness (as a response to information), cortical control of autonomic centers of the brainstem, as well as the vagal flow to the heart, contribute to the self-regulation process (Di Bello et al., 2024; Porges, 2001). HRV, the difference in heart rate between beats, is one sign of vagal parasympathetic activity (Montaquila et al., 2015). Self-regulation brain structures also govern the nervous system, HRV has been recognized in physiology as a measure of self-regulation ability (Segerstrom and Nes, 2007).

The Attention Restoration Theory (or ART) suggests that directed attention is recharged by interacting with nature (Kaplan and Berman, 2010).

Moreover, exposure to nature scenes allows for renewal physiologically, for example, the inducement of parasympathetic system reactions, which lead to more self-regulation (Berto, 2014; Sun et al., 2022e). Also, ART show that self-regulation and executive function depend significantly on directed attention as a fundamental resource (Kaplan and Berman, 2010). In this scenario, nature scenes may increase the capacity of self-regulation among mentally fatigued players, and let them better regulate physiological (HRV) and psychological state (competitive state anxiety: CSA).

Despite growing evidence linking MF to decreased soccer performance (Filipas et al., 2021; Fortes et al., 2023), interventions to mitigate its effects remain limited. This study addresses this gap by exploring nature exposure as a potential method to restore self-regulation in mentally fatigued athletes. This is important because understanding how to alleviate MF can directly enhance player performance, especially in sustained high-intensity sports like soccer. Sun et al. (2022a) recently examined nature exposure with three different durations (4.17, 8.33, and 12.50 min) in mentally fatigued soccer players and found an improvement in MF and decision-making skills. Notably, the 12.50 min intervention yielded the most significant improvements. Several questions were raised, for instance, could the improvement be from increased self-regulation? Does longer intervention have greater restorative effect? Perhaps mentally fatigued players could regain self-regulation more effectively after longer interventions, allowing them to better concentrate on relevant tasks such as soccer decision-making. Therefore, the current study was to measure HRV and CSA as the indicator of physiological and psychological self-regulation) to examine the potential mechanism by which nature exposure affects mentally fatigued soccer players.

The following hypotheses were formulated: H1: Nature exposure significantly enhances self-regulation in mentally fatigued soccer players, as measured by improvements in HRV and reductions in CSA. H2: The impact of nature exposure on restoring self-regulation is dependent on the duration of the exposure, with longer exposure times leading to greater improvements compared to shorter durations.

Methods

Participants

G*Power 3.1 in repeated ANOVA within-between interaction measurements was used to estimate the sample size. The effect size calculation for this study is informed by the declarative knowledge from previous studies (Sun et al., 2022a; Wang et al., 2016), which was conducted in China and gave two virtual nature exposure groups mean and standard deviation: 4.63 ± 0.76; 4.96 ± 0.75 for the parameter of perception of restorativeness, respectively. Inputted into G*Power, a prior computation required the sample size and the independent t-test. Cohen's d was estimated to be 0.437. As a result, the effect size f, equals 0.2185. Ninety male university soccer players volunteered for this randomized, between-subjects study (duration of training: 5.14 ± 1.30 years; age: 20.73 ± 2.00 years). The study recruited male players only due to gender differences in responses to cognitive demand (Pereira et al., 2015; Yoon et al., 2009).

Two Chinese university soccer teams' players were randomly divided into six groups: one for each of the three experimental groups and one for each of the three control groups. They completed informed consent forms and received written instructions explaining the protocols of the studies, which were authorized by the ethics committee of Universiti Putra Malaysia (Program number: JKEUPM-2020-327) and adhered to the Helsinki Declaration. On 05/01/2021, the protocol was registered on ClinicalTrials.gov with Identifier NCT04693481. The objectives of the investigation were not disclosed to the participants; however, they were told that the study was "examining soccer-specific talent following a standard pre-game activity."

All subjects considered fulfilled the inclusion criteria: (i) university soccer players (age 18 to 24 years); (ii) over three years of training experience; (iii) no sleeping difficulty; (iv) not goalkeepers; and (v) no color blindness.

Development of stimuli material

The stimuli material in the current study mainly is restorative environments. Since nature is a source of "soft fascination" (Herzog et al., 1997), which is the most important property of restorative environments Berto (2005). The current study additionally recruited an expert panel to help evaluate and select certain stimuli according to the definitions of the nature scenes.

In particular, nature scenes, such as forest land and national parks, are typically devoid of human-made artifacts but are not wholly ungoverned by humans (Balling and Falk, 1982). Consequently, nature's dominance is not limited to the wilderness (Ulrich, 1983). In general, Asian adults consider situations as natural if they meet 3 criteria: (i) the prevailing outlines are curvilinear or uneven (Han, 2003; Ulrich, 1983); (ii) non-natural aspects are not concealed; and (iii) the scenery is obscured by foliage, water, and mountains.

According to some studies, another criterion should also be considered. The nature settings without humans were more restorative (Staats, 2012; Wang et al., 2016). They dubbed this individual "the absence of humans". The current study selected a variety of nature scenes in which "humans are absent".

First, the Department of Photography at Zhongyuan University University of Technology (ZUT) provided a massive collection of photographs of natural settings captured by numerous instructors during prior outdoor photography classes in China. Next, to comply with the photo criteria, two experts (see Table 1 for details) were enlisted to select suitable photos. The 1st examined photographs following the concept of natural settings and the extension to Asian people. The 2nd expert evaluated the photographic quality of the images to confirm that they were chosen suitably and did not contain color or shape distortions, as well as horizontal views at eye level.

Table 1. Selection results of stimuli material.

Ref	Experts Specialization	Institution	Selection Results
1	Environmental Design	ZUT	78
2	Photographic Aesthetics	ZUT	50

Objectively, two expert rating forms (supplementary document: Table S1 and Table S2) were created according to the definitions and the quality of nature scenes for the selection. And they were given to two experts, respectively. Each item in the form was evaluated through a dichotomous result. The first expert evaluated with Table S1 according to the definitions. Subsequently, the second expert was evaluated in Table S2 (supplementary document). The photos that only fulfill all the criteria were selected (Table 1: Selection Results). Finally, fifty color photos were chosen and represented various natural settings, including oceans, rivers, lakes, seas, hills, forests, and mountains.

Following Berto (2005), the subsequent growth process proceeded as expected. At ZUT, forty students (M = 20.90 ± 2.00 years; male 28 and female 12) contributed to developing the stimuli of the experiment. This was done with five sets of ten photos, one for each setting, with eight male students evaluating each set. Each participant evaluated the restorative effect of each image with the perceptual restorativeness scale. The photography department's lab was used to test individuals and small groups of no more than four students. To get participants comfortable with the procedure, the researcher presented two practice slides. Five slides were then presented and rated. To prevent participants from becoming overly familiar with the task, a brief diversion exercise was implemented, which involved counting backward by sevens from 100 to 0. They then showed and reviewed the final five slides. The stimuli images were then selected using an average across the perception restorativeness scale. The top 25 photographs (mean = 9.455 to 7.364) were selected.

Furthermore, the researcher was unable to obtain urban images for the control groups because of the pandemic. As a result, photographs used in Berto (2005) were employed to provide a visual contrast to nature stimuli such as industrial zones, housing, city streets and porches.

Measures

The instruments used have three measurement tasks:

(i) measurement of the dependent variable (HRV and CSA); (ii) MF inducement (45 min Stroop task) and measurement (visual analog scale); (iii) and measurement of the control variables. These instruments are discussed in the next section.H10 Polar and EliteHRV.

Each person measured HRV using a chest strap (H10 Polar) and the EliteHRV phone app. Elite HRV has been validated as a legitimate application due to its high correlation with the Kubios HRV analysis program (r = 0.92) (Perrotta et al., 2017). The Inter-assay coefficient of variation for HRV measurements in this study was 3.78%, indicating excellent consistency across different measurement sessions (supplementary document: Inter-assay coefficient of variation, Table S4).

Competitive State Anxiety Inventory-2:

The CSAI-2 was utilized to investigate competitive state anxiety (Martens et al., 1990). The CSAI-2 is the multidimensional evaluation of an athlete's thinking and effect regarding competition during time. The inventory has a total of 27 elements and was completed in about five minutes on a hardcopy. Each item is graded on a Likert scale that ranges from 1 ("Not at all") to 4 ("Very much so"). The 27-element assessment is divided into three nine-item subscales: cognitive-based anxiety (e.g., "I feel nervous"), somatic-based anxiety (e.g., "My heart is racing"), and confidence (e.g., "I feel self-confident"). Every subscale generates a unique value between 9 and 36. Within each subscale, scores are summed, with lower values suggesting less anxiety (confidence) and larger values suggesting increased anxiety (or confidence) (Martens et al., 1990). Cognitive anxiety subscales (Cronbach α = 0.75), somatic anxiety subscales (Cronbach α = 0.79), and self-confidence subscales (Cronbach α = 0.77) were found in athletes (Fernandes et al., 2013). The current study adopted the measurement in Chinese culture, which showed two domains (cognitive and somatic anxiety, and self-confidence).

Stroop task

MF was achieved with the use of a 45-minute computer version Stroop task created using "E-Prime". The digital Stroop task has been shown in numerous studies to successfully induce MF in soccer players (Gantois et al., 2019; Moreira et al., 2018; Smith et al., 2015; Smith et al., 2016b; Trecroci et al., 2020).

Visual Analogue Scale (VAS)

Two Scott Paper Company employees initially established the VAS and used it to evaluate subordinate staff. Ahearn (1997) established conclusively that the VAS is an effective instrument for measuring mood. It is efficient in measuring mental tiredness in athletes (Badin et al., 2016; Smith et al., 2016a; 2016b). To measure the effect of mental exhaustion, participants shifted one vertical line 100 mm horizontally to represent MF. The VAS has two anchors: "0" represents "no weariness" and "100" represents "maximum" fatigue. In addition, motivation was also evaluated by the VAS for the forthcoming tasks.

Brief Trait Self-control Scale (BTSC)

The BTSC was created by Tangney et al. (2004) and has 13 items: five items for capacity for self-discipline, three for deliberate actions, two for healthy eating habits, two for work ethic and one for dependability. Participants evaluated every item using a 5-point Likert scale ranging from 1 (not at all true) to 5 (completely true). Meanwhile, Unger et al. (2016) established that the BTSC has an internal consistency that is considered acceptable (Cronbach's Alpha = 0.75) as well as a significant correlation with the entire self-control trait scale.

Perception of Restorativeness Scale (PRS)

The perception of restorativeness scale was developed to assess a person's impression of four restorative elements (being remote or away; extent; fascination; and compatibility). It was created by Pasini et al. (2014) with ∝ = 0.89 and was recruited by several studies (Cassarino et al., 2019; Hyam, 2017; Keller et al. 2021). Eleven items were evaluated on a 10-point scale, with 0 indicating "not at all," 6 indicating "rather much," and 10 indicating "completely" Pasini et al. (2014).

Design and procedure

A randomized controlled trial with a between-subject design was recruited for experimental and control groups. Using a website (www.randomizer.org), the experimenter randomly divided all soccer players into six groups (Figure 1). Notably, to assess the effect of varied durations following the study of Sun et al. (2022a), three comparisons were conducted with six groups exposed to the intervention for 4.17 min (experimental group 1 vs. control group 1; 10s for each stimulus), 8.33 min (experimental group 2 vs. control group 2; 20s for each stimulus), and 12.50 min (experimental group 3 vs. control group 3; 30s for each stimulus), respectively.

Before the trial, ITQ evaluated and assessed the trait-immersive tendencies of all participants. It ensured that each group's characteristics were comparable. Following recruitment, athletes participated in two courses (familiarisation and testing session). During the familiarisation session, the instruments were described. In addition, participants were instructed to get eight hours of sleep, avoid alcohol consumption and excessive activity within twenty-four hours and caffeine.

During the testing session, four phrases were displayed one by one (red, blue, green, and yellow). All nighty participants must ignore the phrases' meaning and identify their color. In contrast, when the phrase's ink color was red, the appropriate response was based on the meaning of the word rather than its color. To correctly answer, participants were told to press the keyboard button matching the displayed phrases' color. Each phrase was displayed for 1000 milliseconds in 100-point typography, followed by 1500 milliseconds of a blank screen until the next word was presented. Thus, a new phrase was displayed every 2500 milliseconds, totalling 1080 stimuli (45 minutes). The speaker of the computer sounded a beep if a response was missing or incorrect (>1700 milliseconds).

After the 45-min Stroop task pre- and post-test measurements were taken, followed by three distinct intervention durations (Figure 1). There were no classes before the tests on weekends, so all participants began testing at 10.30 a.m. A competitive environment was created to increase stress, prompting participants to complete the Stroop task as accurately and quickly as they could. The experiments were conducted in the lab and with double blinded design.

Intervention

Following the pre-test, the intervention began. One meter away, players would be seated in front of a computer. The space was dimly lighted and free of distractions, forcing people to concentrate on the television. The instructor explained to the players that: (i) a series of photos would be displayed, and (ii) there was no other assignment, so they may view all photographs at their leisure. The experimental groups viewed virtual nature photographs for 4.17, 8.33, and 12.50 minutes, while the control groups viewed urban photographs. Just after the intervention block, the post-test was administered to the participants.

Statistical analysis

Using skewness and Kurtosis analyses, the data distribution was evaluated. The Levene's test was conducted by one-way ANOVA to examine the homogeneity of the perception of restorativeness, as well as demographics in six groups. The mean and standard deviation are provided for all data. In addition, a two-way (condition × time) mixed ANOVA test was utilized as the primary analytical method and evaluate the mean of MF, HRV, and CSA in between experimental and control groups.

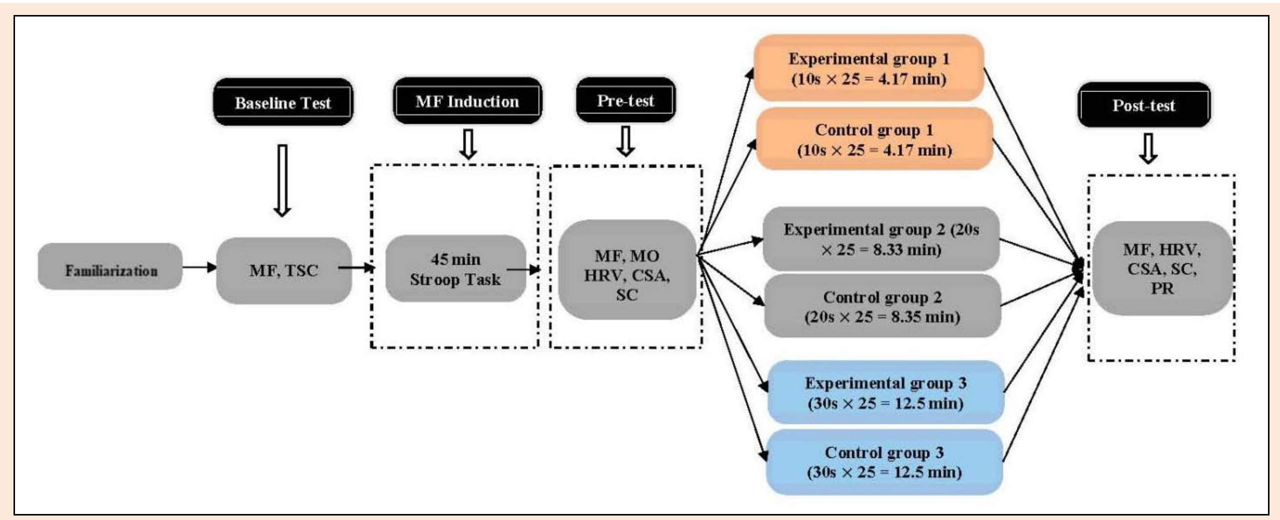

Figure 1. Experimental design. MF: mental Fatigue; TSC: trait self-control; MO: motivation; IT: immersive tendency; PR: perception of restorativeness; HRV: heart rate variability; CSA: cognitive and somatic anxiety; SC: state confidence.

Since there is a moderate correlation ($r = 0.32$, $p < 0.01$) (see the supplementary document: Determination) detected between motivation and the dependent variable of cognitive and somatic anxiety, the variable of motivation was recognized as a potential covariate and a two-way repeated measures ANCOVA was employed. Therefore, the additional assumption for ANCOVA was addressed (e.g., homogeneity of regression). Overall, no interactions were detected and all assumptions were not violated, except the sphericity assumption for the MF parameter was violated with $p = 0.004$ (supplementary document: Table S3). Thus, the F-value of MF was adjusted by a Greenhouse-Geisser correction. The details for all assumption testing are shown in the supplementary document (Assumption Testing). To determine statistical differences, Bonferroni post-hoc tests were applied. The data were analyzed in SPSS 26.0 using a significance level set at 5%.

Results

Demographic and control measures

Fifteen participants were assigned into each group and there were no participants dropped out from the experiment. The homogeneity of demographic characteristics shows in each group (duration of training: $F_{(5,84)} = 0.14$, $p = 0.98$; age: $F_{(5,84)} = 0.04$, $p = 0.99$). All participants were university soccer players, holding either a first- or second-class athlete certification, indicating their competitive level. These certifications correspond to players competing at regional level, representing their universities.

Table 2 also showed no significant variances among the six groups regarding immersive tendency ($F_{(5,84)} = 0.06$, $p = 0.10$), which means the character of immersing as well as one's attention to pressing tasks is similar for the six groups. Additionally, the perception of restorativeness showed significant differences in six groups ($F_{(5,84)} = 47.86$, $p < 0.01$) (Table 2).

Significant differences were found (Table 3) between each comparison between control and experimental groups (experimental group 1 vs. control group 1; experimental group 2 vs. control group 2; and experimental group 3 vs. control group 3) ($p < 0.01$) at post-test.

Mental fatigue measures

As shown in Table 3, a statistical significance was detected either in the within-subject test ($F_{(1,84)} = 36.44$. $p < 0.01$, $\eta^2 = 0.30$) or interaction ($F_{(1,84)} = 3.86$, $p < 0.01$, $\eta^2 = 0.19$), respectively, indicating the variations in MF conditions throughout time were significant for six groups. Groups had no statistically significant main impact ($F_{(1,84)} = 0.43$, $p = 0.83$, $\eta^2 = 0.03$). Based on the Bonferroni assessment, the MF difference between baseline and pretest was statistically significant ($p < 0.05$) across all six groups (see Table 3). Moreover, the changes in MF were still statistically significant between the baseline test and post-test for the three control groups ($p < 0.05$), whereas there were no significant variances among the three experimental groups. Finally, significant changes were found in experimental groups 2 and 3 after the intervention (from pre-test to post-test). Notably, only experimental group 3 showed significance when compared with corresponding control group 3 (Table 3).

Table 2. **Mean scores (plus standard deviations) for variables.**

Variable	Experimental Group									
	Exp 1	Con 1	Exp 2	Con 2	Exp 3	Con 3	Effects	*F*	*P*	η^2
Age	20.73 (2.37)	20.53 (1.96)	20.87 (2.20)	20.73 (2.02)	20.73 (1.94)	20.80 (1.82)	Group	0.04	0.99	
DOT	5.33 (1.35)	5.00 (1.73)	5.20 (1.15)	5.13 (1.30)	5.00 (1.25)	5.20 (1.21)	Group	0.14	0.98	
Mental Fatigue										
Baseline test	2.79 (1.52) *	2.71 (1.14)**	2.59 (1.17) *	2.42 (1.15)**	2.71 (1.06) *	2.41 (1.21)**	Group	0.43	0.83	0.03
Pretest	3.61 (1.25)	3.50 (1.09)	3.47 (1.04)	3.53 (1.62)	3.65 (0.87)	3.37 (1.32)	Test	36.44	<0.01	0.30
Posttest	3.19 (1.25)	3.53 (0.87)	2.57 (0.85) *	3.59 (0.10)	2.27 (0.95) *#	3.49 (0.93)	Interaction	3.86	<0.01	0.187
PR	96.40 (11.86)	65.00 (7.50)	92.27 (9.92)	67.13 (6.55)	95.60 (8.93)	69.60 (6.72)	Group	47.86	<0.01	
HRV										
Pretest	2..62 (1.26)	2.48 (1.10)	2.55 (1.08)	2.66 (0.95)	2.42 (1.29)	2.68 (1.15)	Group	1.72	0.14	0.09
Posttest	2.46 (0.96)	2.55 (1.00)	1.81 (0.66) *	2.70 (0.77)	1.52 (0.81) *#	2.64 (0.86)	Test	6.28	0.01	0.07
							Interaction	2.19	0.06	0.12
Cognitive and Somatic Anxiety										
Pretest	40.93 (8.57)	41.00 (8.42)	41.07 (8.51)	41.00 (9.15)	40.133 (8.98)	41.13 (7.80)	Group	1.46	0.21	0.08
Posttest	40.40 (9.07)	41.20 (8.27)	36.20 (9.50) *	41.13 (9.92)	30.27 (7.41) *#	41.20 (9.31)	Test	0.50	0.48	0.01
							Interaction	4.57	<0.01	0.22
State Confidence										
Pretest	26.40 (4.21)	25.80 (3.12)	25.93 (4.38)	26.80 (5.36)	25.60 (4.47)	25.20 (5.06)	Group	1.08	0.38	0.06
Posttest	27.47 (3.91)	26.00 (4.44)	30.00 (4.09)	26.53 (5.42)	30.27 (3.58)	25.27 (4.94)	Test	17.25	<0.01	0.17
							Interaction	5.08	<0.01	0.23

* p < .05 versus Pretest; # p < .05 versus corresponding control group; ** p < .05 versus Pretest and Posttest; PR: perception of restorativeness; DOT: duration of training; HRV: heart rate variability; CSA: competitive state anxiety.

Table 3. **Pairwise comparison across groups for perception of restorativeness.**

Group		Mean Difference	SE	P	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
Con 1	Exp 1	-31.40*	3.21	<0.05	-40.75	-22.05
Con 2	Exp 2	-28.13*	3.21	<0.05	-37.49	-18.78
Con 3	Exp 3	-26.00*	3.21	<0.05	-35.35	-16.65

* Mean difference is significant at the 0.05 level; [b] Adjustment for multiple comparisons: Bonferroni.

HRV and competitive state anxiety measures

As reported in Table 3, the within-subjects effect (Test) in the indicator of physiological self-regulation (HRV: LF/HF) was statistically significant ($F_{(1,84)} = 6.28$. $p = 0.01$, $\eta^2 = 0.07$). These findings suggest that the interaction was not statistically significant between group and time ($F_{(1,84)} = 2.19$. $p = 0.06$, $\eta^2 = 0.12$), showing that the variations in HRV in the six groups were not very different over time. Furthermore, the group effect was not statistically significant ($F_{(1,84)} = 1.72$. $p = 0.14$, $\eta^2 = 0.09$).

Although no significance shown in the interaction effect, post-hoc tests were employed to provide valuable insights into specific group differences. Specifically, in experimental groups 2 and 3, the changes in HRV mean score from pre- to post-tests reached statistical significance ($p < 0.05$). Moreover, a significant difference was found in the third comparison between control group 3 and experimental group 3 ($p = 0.04$).

Regarding the indicators of psychological self-regulation, cognitive and somatic anxiety showed statistical significance in terms of interaction ($F_{(1,84)} = 4.57$. $p < 0.01$, $\eta^2 = 0.22$). In experimental groups 2 and 3, a follow-up test showed statistically significant ($p < 0.05$) between pre- and post-test in experimental groups 2 and 3. In contrast, no significant differences were observed in other groups regarding the within-subject effect. In addition, only a statistical significance ($p = 0.02$) was identified between experimental group 3 and control group 3.

Consistently, state confidence showed significant changes after the intervention in experimental groups 2 and 3 ($p < 0.01$) from pre- to post-test, rather than in other groups. Moreover, when compared to their respective control group, only experimental group 3 displayed a significant difference ($p = 0.04$).

Discussion

The study found that nature exposure significantly improved self-regulation in mentally fatigued soccer players, with the 12.50-minute intervention showing the greatest effect. This supports the idea that longer exposure durations enhance both physiological and psychological restoration. These results align with the ART, suggesting that nature scenes effectively replenish depleted mental resources.

Mental fatigue inducement and recovery

The current study detected a significant increase of the status of MF from pre-test to post-test in six groups. In line with Sun et al. (2022a), the current study revealed that the 45-min Stroop task induced MF successfully. VAS measured a significant increase from baseline to pre-test in each group. This result aligns with prior work (Badin et al., 2016; Cao et al., 2022a; 2022b; Gantois et al., 2019; Smith et al., 2016a; 2017; Van Cutsem et al., 2017).

There has been a debate about the duration of cognitive tasks applied to achieve MF. Typically, the duration used is 30 min in soccer players (Sun et al., 2022d; Sun et al., 2021; Van Cutsem et al., 2017); however, McMorris (2020) indicates that shorter-duration cognitive tasks generate larger negative effects than longer tasks because of learning effects. The current study spent 45 min, which was longer than 30 min, and the result showed that it was adequate to induce MF significantly. Spending 45 min on a smartphone app can lead to MF among soccer players (Fortes et al., 2019).

The current study found a significant recovery after nature exposure in experimental group 2 and experimental group 3 from pre-test to post-test, consistent with ART. Based on ART (Kaplan, 1995; Kaplan and Berman, 2010), the recovery might be due to the nature that attracts involuntary attention in restoring directed attention. The same result can be found in some experimental studies (Berman et al., 2008; Berto, 2005; Lee et al., 2015; Zhang et al., 2017). However, the duration of 4.17 min in experimental group 1 was not enough for restoring as there was no significant decrease from pre-test to post-test. Previously, Chow and Lau (2015) recruited a similar duration of nature exposure, however, got different results, which showed 4-minute intervention is effective in restoring directed attention and decreasing MF. This inconsistency is probably attributed to the previous mental exertion task. Chow and his colleagues employed a 6-minute cognitive task to induce MF. This is significantly shorter than the 45 min used in the current study. The participants in the current study may have been more mentally fatigued. Thus, the short duration (experimental group 1: 4.17 min) of intervention could not produce counteractive effect.

In contrast, the control groups did not show a significant change from pre-test to post-test, indicating that the MF condition remained unchanged after the intervention. Previous studies have demonstrated cognitive skills are improved by exposure to nature rather than the urban environment. For example, Berto et al. (2010) indicated mentally fatigued subjects cost less when performing an ad hoc attention-orienting task in a high fascination (e.g., nature scenes) compared with a low fascination (e.g., urban scenes) environment. Laumann et al. (2003) showed nature exposure replenishes voluntary attention and has an improved effect on information processing. Typically, the low fascination scenes were recruited in urban environments.

The key concept of the ART is fascination (Berto et al., 2008; Ohly et al., 2016). It drives effortless-interest attention, and typically can be categorized as high (e.g., nature) and low (urban) fascination. Berto et al. (2008) showed that eye movements are different when people view high and low fascination during the experiment. Specifically, when viewing fascinating photographs, people frequently fixated and showed greater scrutiny. The reduced number of fixations in a high fascination environment indicated that people viewed it with less effort. This viewing pattern for high-fascination scenes is called “soft fascination” (Kaplan and Berman, 2010), which is inconsistent with urban scenes in the current study.

Effects of nature scenes on HRV and competitive state anxiety

The current study checked both physiological (HRV: LF/HF) and psychological (cognitive and somatic anxiety, and state confidence) indicators of self-regulation. Overall, there was a sign that nature exposure improved self-regulation in mentally fatigued players in experimental groups 2 and 3.

HRV has been shown to be a reliable marker of autonomic nervous system regulation and is directly related to self-regulation capacity. Higher HRV indicates better balance between sympathetic and parasympathetic nervous systems, which contributes to more effective self-regulation (Segerstrom and Nes, 2007). In this study, the lower LF/HF ratio observed in experimental groups 2 and 3 after nature exposure suggests that the parasympathetic activity was enhanced, allowing players to recover more effectively from cognitive exertion. This result aligns with prior work indicating that nature exposure supports parasympathetic nervous system activity, which plays a key role in stress recovery and mental restoration (Berntson and Cacioppo, 2004; Thayer, 2009).

HRV has been associated with stress (Berntson and Cacioppo, 2004), as well as cognitive exertions (Segerstrom and Nes, 2007; Thayer, 2009). Nevertheless, the current study is not able to differentiate cognitive exertion and stress. Therefore, future studies can explore methods to distinguish these two factors.

It is important to note that not all methods to analyse HRV are equally accurate. The current study utilized the LF/HF ratio**,** which is a widely used method for assessing autonomic balance (Shaffer and Ginsberg, 2017). However, it is recognized that this method has certain limitations, especially regarding its ability to distinguish between sympathetic and parasympathetic activity in all contexts (Billman, 2011; Rajendra Acharya et al., 2006). Additionally, comparisons with other studies should be interpreted cautiously due to potential methodological differences. For example, some studies might use time-domain measures (e.g., RMSSD) (Umetani et al., 1998) or non-linear methods (e.g., Poincare plots) (Khandoker et al., 2013), which can yield slightly different insights into HRV. The current study followed standard protocols and validated methods (EliteHRV), ensuring that the data collected aligns with reliable physiological indicators, but future research could benefit from employing multiple HRV analysis techniques to provide a more comprehensive picture.

Regarding psychological self-regulation, the current study examined CSA from two aspects: (a) cognitive and somatic anxiety; and (b) state confidence. A significant interaction effect was found in these two aspects, which meant that the control group and experimental group reported different levels of anxiety and confidence. This result is in line with previous findings on physiological self-regulation. The soft fascination of nature scenes attracted attention and restored directed attention leading to an increase in the limited resource pool in self-regulation. This process suggests that directed attention may be a common resource of self-regulation as indicated by ART (Kaplan and Berman, 2010). Thus, self-regulation is increased along with directed attention. Previous studies have found that exposure to nature reduces anxiety levels (Ulrich et al., 1991; Wang et al., 2016). After 8.33 min and 12.50 min of interventions, mentally fatigued players increased their self-regulation ability and can control their CSA better.

Previous studies showed that a short duration of nature exposure (e.g., 1.5 - 6 min) could restore their self-regulation significantly (Beute and de Kort, 2014; Chow and Lau, 2015). However, the current study did not approve the short duration of intervention in experimental group 1 (4.17 min) either from pre-test to post-test or compared with control group 1. This difference is attributed to the difference in prior cognitive tasks. Beute and de Kort (2014) and Chow and Lau (2015) recruited a 5-minute letter task as the prior cognitive task, which was much shorter than the current study (45 min). Thus, the subjects in the current study may experience more MF as the short duration of intervention cannot induce improvements.

Effects of different durations of nature exposure intervention

The duration issue was first raised by Berto (2005). Stevenson et al. (2018) also recommended future work to investigate the duration issue in the prestigious systematic review. The current study also found that the longer duration of nature exposure was better in improving the subsequent performance as improved trends were found from experimental group 1 to experimental group 3 at the post-test of self-regulation indicators (HRV, cognitive and somatic anxiety, and state confidence).

Based on ART, directed attention might relax when nature scenes draw involuntary attention (Kaplan and Berman, 2010). Therefore, the time of drawing involuntary attention is crucial for restoring directed attention. When the quality of nature scenes is held constant, the time of the exposure can decide the following enhancement. The optimal length to develop self-regulation capacity in mentally weary collegiate athletes is 12.50 minutes, since experimental group 3 improved self-regulation more than the other experimental groups.

Moreover, the findings also support that the longer duration of nature exposure is better (Berman et al., 2008; Thayer, 2009). In other words, shorter duration is less efficient, thus, there was no significance in experimental group 1 and the effect of the intervention had a trend to increase from experimental group 1 (4.17 min), experimental group 2 (8.33 min) to experimental group 3 (12.50 min).

Notably, since some studies showed that long time (e.g., 30 min) screen exposure could induce fatigue (e.g., Fortes et al., 2021a; 2021b; 2021c), it prompts several questions. For instance, could the subjects be fatigued again, if the images are shown for an extended period, suggesting an inverted U-shaped relationship? Perhaps more likely, there may be a cut-off point after 12.50 min that subjects could not benefit from the intervention.

Similarly, Berto (2005) instructed participants to choose how long to look at restorative scenes by themselves. The results showed that participants viewed less duration than the standard exposure time (15 s) shown in experiment 1 to renew their attentional ability. That means participants may "defend" any negative effects from a certain cut-off point and select a shorter time. In contrast, the current study fixed exposure time due to the difference in prior mental exertion (the current study: 45 min Stroop task vs. Berto study: 5 min Sustained Attention to Response Test). Perhaps the participants were more mentally fatigued due to the duration of prior mental exertion was much longer and they needed more time to recover. Therefore, future studies may investigate more on the cut-off point of natural exposure intervention after different prior mental exertion.

The current study recruited soccer players, because self-regulation is highly related to their career (Toering et al., 2009), and directly influences their sports performance (Englert and Bertrams, 2012). Moreover, some studies indicated that the counteractive intervention for MF, improving subsequent soccer performance largely lacks (Sun et al., 2021). Thus, the current study holds potential for future studies to examine the interventions from a self-regulation perspective. Especially, Martin et al. (2019) showed people who have a higher ability for self-regulation could be less susceptible to MF. On the other hand, the current study highlights the caution, that is, the findings may not translate to other populations, because soccer players have their psychological characteristics (e.g., trait self-control: Englert, 2016).

To summarize, the current study was consistent with Sun et al. (2022a) and identified mechanism underlying the improvement in soccer players. Specifically, it demonstrated that mentally fatigued players could better focus on relevant tasks in soccer performance, due to the restoration of directed attention through exposure to nature. Also, the improved HRV and CSA could indicate there was a significant enhancement in self-regulation. Probably, players could better regulate their inner state (e.g., stress or attention) and block out external stimuli (e.g., clusters from audiences).

Limitation

The limitation of the study should be acknowledged. Firstly, all the participants in the current study were male university soccer players, thus, the results could not be generalized to female players, because they have different biopsychosocial factors relating to fatigue (Bensing et al., 1999).

Secondly, the MF condition is induced by a prolonged computerized Stroop task (45 min). Even, though several similar cognitive demands (e.g., inhibition and sustained attention) are also present during games, players are usually not involved in this task before training or competitions. Future studies could measure player's MF during the pre-pitch period in the actual situation (Di Bello et al., 2024; Thompson et al., 2020).

Thirdly, the current study recruited a restorative environment, which has been developed in recent years (from an outdoor photography course at ZUT). However, due to the pandemic, it was unable to obtain photos from an urban setting for the control groups. Therefore, the current study compared urban photos from Berto (2005) to natural stimuli. The stimuli still work according to Berto's suggestion. The most recent study in this field also recruited these stimuli materials (Hicks et al., 2020).

Finally, there are two reasons that the urban photos were chosen for control groups: (i) players typically also checked urban scenes when they had MF; (ii) previous work that investigated interventions of nature exposure to counter MF also selected non-restorative stimulus or low fascination (or urban scenes) as a placebo for the control group (Bratman et al., 2015; Pilotti et al., 2015; Wang et al., 2018). Control groups that are devoid of content may be implemented in future work. That is, players simply rest for a predefined time frame.

Conclusion

The impact of natural exposure on self-regulation in mentally fatigued soccer players was empirically investigated in this study. The results indicated that the intervention substantially improved self-regulation indicators, including HRV and CSA, which reflect both psychological and physiological aspects. Notably, a 12.50 min was identified as the optimal duration for the intervention. These findingss have significant theoretical implications for comprehending the restorative effects of nature exposure on MF, and practical implications for coaches and players in designing effective recovery strategies to enhance performance.

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Key points

- Nature exposure helps restore directed attention and enhance self-regulation by promoting parasympathetic nervous system activity.
- A 12.50-minute nature exposure as an effective intervention to restore self-regulation in mentally fatigued soccer players, offering a practical strategy that can be easily implemented by coaches and teams.
- Integrating nature exposure into pre- or post-training sessions could mitigate the negative effects of mental fatigue, potentially improving the consistency of soccer player performance.

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Supplemental Materials

Two-way Repeated Measures ANCOVA Determination

1) Determination

A one-way ANOVA was recruited to determine whether game position and sports level were correlated with the dependent variables or not. The result showed that there were no significant differences at pre-test of dependent variables for game position and sport level (Table S1).

Table S1. Correlation of confounding factors toward categorical data of variables.

	Variable	Df	MF	F	Sig.
Game Position	ACC1	2	12.299	.379	.685
	RT1	2	4.507	1.495	.230
	HRV1	2	.350	.277	.759
	CPA1	2	80.090	1.150	.322
	SC1	2	26.173	1.367	.260
	MF1	2	1.350	.953	.390
	RPE1	2	1.011	.623	.539
Sport Level	ACC1	2	20.055	.622	.539
	RT1	2	7.804	2.656	.076
	HRV1	2	2.080	1.699	.189
	CPA1	2	31.268	.442	.644
	SC1	2	6.467	.330	.720
	MF1	2	.338	.235	.791
	RPE1	2	2.602	1.641	.200

Moreover, Pearson correlation was recruited to determine whether the continuous data (age, duration of training, motivation, and trait self-control) were correlated or not. One moderate correlation ($r = 0.324$, $p = 0.002$) between pre-test motivation (**MO1**) and pre-test cognitive and somatic anxiety (**CSA**) was found. Therefore, analyses were applied to two-way repeated ANOVA, except for the variable of CSA, which was applied to two-way repeated ANCOVA (Table S2)

Table S2. Correlation of confounding factors toward continuous data of variables.

		MO1	MO2	TSC	Age	Training duration
HRV1	r	-0.086	-0.091	0.153	-0.035	0.079
	p	0.419	0.394	0.149	0.740	0.460
	n	90	90	90	90	90
HRV2	r	-0.086	-0.204	0.235	-0.080	-0.011
	p	0.421	0.053	0.026	0.452	0.920
	n	90	90	90	90	90
CSA1	r	**0.324***	0.167	0.024	0.040	-0.022
	p	0.002	0.115	0.823	0.706	0.837
	n	90	90	90	90	90
CSA2	r	0.123	0.058	0.034	0.121	0.065
	p	0.247	0.589	0.748	0.254	0.554
	n	90	90	90	90	90
SC1	r	-0.067	-0.027	-0.076	-0.096	-0.040
	p	0.530	0.798	0.477	0.369	0.709
	n	90	90	90	90	90
SC2	r	0.129	0.056	-0.141	-0.114	-0.006
	p	0.224	0.598	0.185	0.283	0.952
	n	90	90	90	90	90
MF0	r	0.250	0.127	-0.030	-0.083	-0.019
	p	0.018	0.233	0.782	0.436	0.857
	n	90	90	90	90	90
MF1	r	0.143	0.181	0.056	-0.008	-0.008
	p	0.179	0.088	0.600	0.939	0.944
	n	90	90	90	90	90
MF2	r	0.086	0.138	-0.033	0.013	0.022
	p	0.421	0.195	0.761	0.906	0.839
	n	90	90	90	90	90

*The value is considered to be moderate correlation 1: pre-test; 2: post-test; HRV: heart rate variable; CSA: cognitive and somatic anxiety; SC: state confidence; MF: mental fatigue; MO: motivation; TSC: trait self-control.

2) Assumption Testing

Besides normality, homogeneity test of variance, and sphericity, Homogeneity of Regression and Linearity are other two assumptions should be tested to apply ANCOVA.

Homogeneity of regression and linearity are another two assumptions of analysis of covariance (ANCOVA). Therefore, to use two-way repeated measures ANCOVA and test the dependent variable of CSA, the regression slopes were checked with the covariate of motivation 1. The results (Table S3) showed that there was not an interaction among cognitive and somatic anxiety, motivation 1 and group, $F_{(5,78)} = 0.456$, p = 0.808; there was not an interaction between CSA and group, $F_{(5,78)} = 0.823$, p = 0.537; there was not an interaction between CSA and MO1, $F_{(1,78)} = 2.874$, p = 0.094. Additionally, the scatterplot was shown in Figure S1.

Table S3. Test of Within-subjects Effects in CPA and MO1.

	Df	MS	F	P
CSA * Group * MO1	5	12.880	.456	.808
CSA * Group	5	23.241	.823	.537
CSA * MO1	1	81.198	2.874	.094

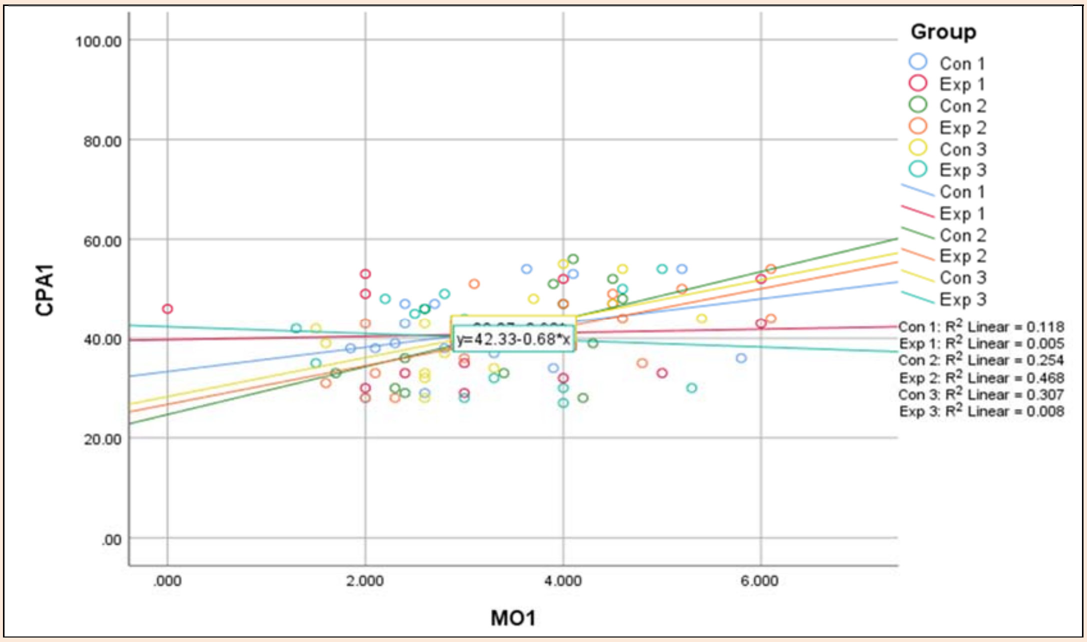

Figure S1. Linearity between MO1 and CSA1.

Inter-assay coefficient of variations

Table S4. Three times measurements.

NO.	Measurement 1	Measurement 2	Measurement 3	Mean	SD	CV
1	78	88	77	81.00	6.08	7.51
2	72	73	76	73.67	2.08	2.83
3	85	87	86	86.00	1.00	1.16
4	86	90	89	88.33	2.08	2.36
5	70	78	77	75.00	4.36	5.81
6	82	81	80	81.00	1.00	1.23
7	79	79	81	79.67	1.15	1.45
8	87	78	88	84.33	5.15	6.53
9	68	74	80	74.00	6.00	8.11
10	78	82	80	80.00	2.00	2.50
11	90	83	89	87.33	3.79	4.34
12	84	85	83	84.00	1.00	1.19
13	88	87	78	84.33	5.51	6.53
14	75	76	77	76.00	1.00	1.32
15	75	81	79	78.33	3.06	3.90

Calculation methods

$$\text{Mean} = \frac{Measurement\ 1 + Measurement\ 2 + Measurement\ 3}{3}$$

$$\text{SD} = \sqrt{\frac{\sum(X_i - Mean)^2}{N-1}}$$

$$\text{CV} = \frac{SD}{Mean} \times 100$$

$$\text{Mean CV} = \frac{\sum CV\ of\ each\ sample}{15}$$