Research Article

Augmented-reality-based exercise increases salivary oxytocin

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Abstract

Purpose: The secretion of oxytocin, which is linked to social interaction, plays a significant role in enhancing human well-being. The utilization of augmented reality (AR) systems can facilitate sustained social interaction irrespective of physical distance. While exercise and sports activities are known to promote oxytocin secretion, the potential benefits of exercise combined with AR remain to be fully explored.

Methods: In a randomized crossover trial, fourteen participants underwent three different regimens: non-exercise (rest), standard cycling exercise (Ex), and cycling exercise combined with AR (Ex+AR). In both exercise conditions (Ex and Ex+AR), participants engaged in self-paced cycling exercises to maintain a Rating of Perceived Exertion of 10. In the Ex+AR condition, participants' avatars were projected onto the tablet screen as they cycled alongside ten other avatars in AR. Saliva samples and mood states (assessed using POMS2) were collected before and immediately after each 10-minute regimen. Subsequently, the levels of salivary oxytocin were measured.

Results: The participants demonstrated a faster speed during Ex+AR compared to Ex, despite there was no difference in self-administered fatigue levels between the two groups. Notably, Ex+AR led to a significant elevation in salivary oxytocin levels, whereas Ex showed a trend toward an increase. Furthermore, only Ex+AR significantly ameliorated mood states related to depression-dejection and exhibited a trend toward suppressing anger-hostility.

Conclusion: These results indicate that Ex+AR facilitates oxytocin secretion and enhances mood states. Employing the Ex+AR system could be a promising means to foster social interaction, transcending physical distances.

Keywords:

Oxytocin, Exercise, Augmented reality, Social interaction

1. Introduction

Following the COVID-19 pandemic, there has been a notable decline in social interaction, potentially elevating the risk of psychological stress and depression (Armitage & Nellums, 2021; Conceição et al., 2021; Klinenberg & Leigh, 2023; Long et al., 2022). Enhanced social interaction has been linked to various benefits, including increased independence, improved psychological and physical health, cognitive function, emotional well-being, and an enhanced quality of life (Cacioppo & Cacioppo, 2014; Kuiper et al., 2015; Mofatteh, 2021). Consequently, developing novel forms of social interaction unaffected by external circumstances is anticipated to impact human well-being positively.

There is considerable anticipation regarding using Extended Reality (XR) technology as a novel approach to facilitate social interaction (Achilleos et al., 2023; Dechsling et al., 2022; Scavarelli et al., 2021). XR technology encompasses a wide range of natural and virtual environments, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) technologies. Its application to enhance human capabilities is burgeoning across various fields, such as sports and medical science (Barteit et al., 2021; Janssen et al., 2023; Le Noury et al., 2023). However, the effectiveness of XR-based communication has shown inconsistency, with some studies reporting its effectiveness in enhancing interaction (Dong et al., 2013; Rogers et al., 2022), while others have found it ineffective (Miller et al., 2019). Thus, thoughtful consideration regarding

utilizing XR technologies to promote social interaction has the potential to introduce innovative ways to contribute to human health.

Oxytocin supports various physiological and psychological responses to social interaction (Auyeung et al., 2015; Yu et al., 2022). It is a nine-amino acid peptide synthesized in the paraventricular nuclei and supraoptic nuclei of the hypothalamus, subsequently secreted from the posterior pituitary gland into circulation. Social behaviors such as affectionate touch and physical proximity enhance oxytocin secretion (Burenkova et al., 2023; Caicedo Mera et al., 2021; Holt-Lunstad et al., 2008; Landgraf & Neumann, 2004). Despite lacking affectionate touch, XR-based communication also enhances oxytocin secretion (Dekker et al., 2021). Previous studies have highlighted oxytocin's role as a suppressor of negative emotions, including depressed mood and anxiety (Galbally et al., 2021; Goodin et al., 2015; Heinrichs et al., 2003; Yoon & Kim, 2022). Moreover, oxytocin is considered a potential biomarker for assessing the effects of social interaction and the development of various psychiatric disorders (Caicedo Mera et al., 2021; Yoon & Kim, 2022). Thus, fluctuations in oxytocin levels in biofluids could indicate responses to social interaction facilitated by XR technologies.

Oxytocin levels are not only upregulated by social interaction but also by exercise. Exercise offers numerous benefits, including disease prevention and the treatment of psychiatric disorders such as depression and anxiety disorders (Deslandes et al., 2009; Hwang et al., 2023;

Laird et al., 2023; Viana & de Lira, 2020). Even light-intensity acute exercise has been shown to enhance mood and prosocial skills in healthy individuals (Basso & Suzuki, 2017; Edwards et al., 2017; Ludyga et al., 2022). These effects of exercise are believed to be partially mediated by oxytocin (Ludyga et al., 2022), as evidenced by reports indicating that brief 10-minute exercises increase salivary oxytocin levels (de Jong et al., 2015). However, previous research has highlighted that the type of exercise can influence differences in oxytocin secretion (Rassovsky et al., 2019), with team sport athletes demonstrating lower levels of anxiety and depression compared to individual sport athletes (Pluhar et al., 2019). While it is hypothesized that combined exercise and utilizing XR technology may offer greater benefits in enhancing oxytocin secretion and improving mood states compared to standard exercise alone, this remains to be confirmed.

Here, we examined the alterations in salivary oxytocin levels and mood state across three experimental conditions: 1. augmented-reality-based exercise (Ex+AR), 2. standard exercise (Ex), and 3. rest. Saliva was chosen as the medium for evaluating oxytocin levels as it provides a reliable indicator of changes associated with interventions (Burenkova et al., 2023).

2. Methods and materials

2.1. Participants

Fourteen Japanese college students (8 men and 6 women, age: 20.5 ± 1.7), who had received instructions and provided consent, participated in the study. Informed consent was obtained from all individual participants prior to their involvement. The Utsunomiya University Ethical Review Board approved the current investigation for Medical Research Involving Human Subjects (ethical number: H23-0012). Participants had no history of neurological, psychiatric, or respiratory disorders, diabetes, anemia, or other medical conditions. Additionally, all participants underwent Ex+AR training prior to the main experiment.

2.2. Experimental procedure

All participants were randomly assigned to undergo all three experimental conditions at one-week intervals: rest, Ex, and Ex+AR. Participants were instructed to refrain from exhaustive exercise, as well as from consuming alcohol and caffeine, for at least 24 hours prior to each experiment. The experimental procedure is shown in Figure 1. Paired participants were simultaneously exposed to the experiment under the same conditions in separate rooms. Participants completed the POMS2 questionnaire, and 1 ml saliva samples were collected after a 10-minute rest period. Following another 10-minute rest, participants engaged in a 10-minute sedentary period, Ex, or Ex+AR. Subsequently, participants completed the POMS2 questionnaire again, and saliva samples were collected. Heart rate (HR) was measured using an HR sensor (H10; Polar Electro, Japan).

2.3. Exercise and augmented reality system

In both exercise conditions (Ex and Ex+AR), participants engaged in self-paced cycling exercises to maintain a Rating of Perceived Exertion (RPE) of 10. Mean speed (km/h) was recorded throughout the 10-minute cycling session using the SmarT Turbo KAGURA (LST9200, MINOURA Co., Ltd., Japan) and the ROUVY application (VirtualTraining Co., Ltd., Czech Republic). During the Ex condition, participants cycled in front of a flipped tablet. In contrast, during the Ex+AR condition, participants cycled in front of a tablet running the ROUVY application. In the Ex+AR condition, participants' avatars were projected onto the tablet screen as they cycled in augmented reality alongside ten other avatars, including the avatar of a paired participant (refer to Fig. 1). Notably, participants did not utilize a headset with the current AR system.

2.4. Saliva collection and measurement of oxytocin concentration

Saliva samples were collected from participants before and immediately after engaging in each experimental condition using the Saliva Collection Aid (Salimetrics, LLC., USA) and Cryovial (Salimetrics, LLC., USA). These samples were stored at -20°C for subsequent analysis. Oxytocin concentrations in the saliva samples were measured in duplicate and calculated following the manufacturer's instructions utilizing the Oxytocin ELISA Kit Wako (FUJIFILM Wako Pure

Chemicals Corp., Japan) and a plate reader (EnSpire® Multimode Plate Reader, PerkinElmer, Inc., Massachusetts, USA).

2.5. Questionnaire

To assess the seven subscales of mood states (anger-hostility, confusion-bewilderment, depression-ejection, fatigue-inertia, tension-anxiety, vigor-activity, and friendliness), as well as total mood disturbance, participants completed the short form of POMS2 (Kaneko Shobo, Japan) before and immediately after each experimental condition. The short form of POMS2 comprises 35 items, with participants responding to a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

2.6. Statistical analysis

The data are presented as mean ± SD and were analyzed using Prism version 10.1.1 (MDF, Japan). Group comparisons were conducted using repeated measures two-way ANOVA (factor 1: time points [pre vs. post]; factor 2: groups [rest vs. Ex vs. Ex+AR]) with Šídák's multiple comparisons test. A comparison between Ex and Ex+AR was performed using a paired t-test (for analyzing mean speed). The correlation between mean speeds and the exercise-induced changes in salivary oxytocin levels (ΔOxytocin) was assessed using Pearson correlation. ΔOxytocin was calculated by subtracting the concentration at pre-exercise from the concentration at post-exercise. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Heart rate and mean speed during cycling exercise

Both the Ex and Ex+AR conditions demonstrated a significant increase in participants' heart rate post-exercise compared to pre-exercise (Fig. 2A, Ex: $p < 0.0001$, Ex+AR: $p < 0.0001$; main effects of time points: $F_{(1.00, 13.00)} = 129.0$, $p < 0.0001$, main effects of group: $F_{(1.90, 24.70)} = 40.6$, $p < 0.0001$, interaction: $F_{(1.52, 19.71)} = 79.8$, $p < 0.0001$). Conversely, participants' heart rate remained unchanged during the rest condition (Fig. 2A, $p = 0.9984$). Despite efforts to maintain an RPE of 10 in both the Ex and Ex+AR conditions, the mean cycling speed was higher in the Ex+AR condition compared to the Ex condition (Fig. 2B; $t = 2.39$, $p = 0.033$).

3.2. The changes in salivary oxytocin

Ex+AR significantly increased salivary oxytocin levels (Fig. 3A, $p = 0.0005$; main effects of time points: $F_{(1.00, 13.00)} = 24.8$, $p = 0.0002$, main effects of group: $F_{(1.84, 23.93)} = 2.30$, $p = 0.1259$, interaction: $F_{(1.94, 25.16)} = 10.0$, $p = 0.0007$), whereas Ex exhibited a trend towards an increase (Fig. 3A, $p = 0.0868$). Salivary oxytocin levels remained unchanged in the rest condition (Fig. 3A, $p = 0.5238$). Furthermore, no significant correlation was observed between cycling speeds and ΔOxytocin (Fig. 3B; $r = 0.1162$, $p = 0.5560$).

3.3. The changes in mood state

Only Ex+AR significantly suppressed the depression-ejection score (Fig. 4C, p = 0.0314; main effects of time points: $F_{(1.00, 13.00)}$ = 6.92, p = 0.0208, main effects of group: $F_{(1.89, 24.57)}$ = 1.53, p = 0.2370, interaction: $F_{(1.61, 20.92)}$ = 0.72, p = 0.4686) and exhibited a trend towards a decrease in the scores of anger-hostility and total mood disturbance (Fig. 4A, H; anger-hostility: main effects of time points: $F_{(1.00, 13.00)}$ = 8.87, p = 0.0107, main effects of group: $F_{(1.46, 18.95)}$ = 0.04, p = 0.9240, interaction: $F_{(1.63, 21.20)}$ = 1.26, p = 0.2960; total mood disturbance: main effects of time points: $F_{(1.00, 13.00)}$ = 7.08, p = 0.0196, main effects of group: $F_{(1.77, 23.05)}$ = 0.95, p = 0.3907, interaction: $F_{(1.70, 22.04)}$ = 1.32, p = 0.2830). Both Ex and Ex+AR showed a trend towards a decrease in the tension-anxiety score (Fig. 4E; main effects of time points: $F_{(1.00, 13.00)}$ = 15.0, p = 0.0019, main effects of group: $F_{(1.88, 24.41)}$ = 1.01, p = 0.3747, interaction: $F_{(1.65, 21.46)}$ = 1.27, p = 0.2941). None of the subscales of mood state or total mood disturbance showed alterations in the rest condition (Fig. 4A-H).

4. Discussion

In this study, we examined the impact of Ex+AR on salivary oxytocin concentration and psychological state compared to Ex. Our results revealed that, despite similar levels of effort compared to the Ex condition, Ex+AR exhibited higher cycling speed, significantly elevated salivary oxytocin levels, and improved mood states.

The current study demonstrated that the mean speed during cycling exercise in the Ex+AR condition was significantly faster than in the Ex condition, despite no difference in heart rate and self-effort level (Fig. 2A and B). Prior research has indicated that utilizing Extended Reality during exercise can reduce human fatigue (Berezina et al., 2022; Plante et al., 2003). The current study demonstrated that the mean speed during cycling exercise in the Ex+AR condition was significantly faster than in the Ex condition, despite no difference in heart rate and self-effort level (Fig. 2A and B). Prior research has indicated that utilizing Extended Reality during exercise can reduce human fatigue.

Salivary oxytocin levels increased significantly only in the Ex+AR condition (Fig. 3A). Since ΔOxytocin did not correlate with cycling speeds (Fig. 3B), it suggests that the use of the AR system could influence oxytocin secretion. Previous research has demonstrated that XR-based communication facilitates social interaction (Dong et al., 2013; Rogers et al., 2022) and oxytocin secretion (Dekker et al., 2021). Therefore, it is plausible that the current Ex+AR approach could elevate salivary oxytocin levels. However, it is worth noting the possibility that using an AR system with a head-mounted display may downregulate perceptual functions in humans (Livingston et al., 2013). Given that participants in the current study did not utilize a head-mounted display with the AR system, future research should investigate the effects of augmented-reality-based exercise while incorporating a headset.

Only the Ex+AR condition significantly suppressed the depression-ejection score (Fig. 4C) and showed a trend towards a decrease in the scores of anger-hostility and total mood disturbance (Fig. 4A, H). Oxytocin has been implicated in reducing depressed mood and anger expression (Domes et al., 2007; Galbally et al., 2021; Goodin et al., 2015; Heinrichs et al., 2003). Therefore, the increase in oxytocin secretion observed in Ex+AR may contribute to improving mood. Additionally, since team sport athletes exhibit a lower risk of anxiety and depression compared to individual sport athletes (Pluhar et al., 2019), the online exercise with multiple participants (ghost riders) in the Ex+AR condition of this study may have produced effects akin to those observed in team sports. A trend towards a decrease in the tension-anxiety score was evident in both the Ex and Ex+AR conditions (Fig. 4E). Although oxytocin is involved in anxiety states (Yoon & Kim, 2022), significant changes in oxytocin secretion were only observed in Ex+AR (Fig. 3A), suggesting that oxytocin may not be directly implicated in exercise-induced tension-anxiety changes.

The current study has several limitations. Firstly, the assessment of social interaction provided by the AR system was based on changes in oxytocin levels. Future studies would benefit from analyzing the quality of social interaction using established methods (Lopes et al., 2004; Reis & Wheeler, 1991). Secondly, the effects of oxytocin and exercise, mediated by oxytocin, may vary among individuals (Shima et al., 2022; Sikich et al., 2021). Therefore, further research is needed to determine whether the current Ex+AR condition effectively enhances human well-being. Lastly, the

study only involved healthy participants. Given that standard exercise has been shown to prevent and treat psychiatric disorders (Deslandes et al., 2009; Hwang et al., 2023; Laird et al., 2023; Viana & de Lira, 2020), there is a possibility that the current Ex+AR approach could serve as a more efficient therapy for such disorders compared to standard exercise alone. Future studies should explore this possibility.

In conclusion, our current findings provide the initial evidence that Ex+AR significantly increases salivary oxytocin levels and enhances mood states. These results would contribute to advancing and developing effective strategies for enhancing social interaction and overall well-being.

Funding:

This work was supported by the Public Health Research Foundation and the Foundation for the Fusion of Science and Technology.

Data availability:

The datasets in the current study are available from the corresponding author on reasonable request.

Declaration of competing interest

The authors inform no conflicts of interest.

Author contribution

TS: Conceptualization, Methodology, Resources, Investigation, Writing–original draft, Writing–review & editing, Funding acquisition; JI: Investigation, Writing–review & editing, HS: Investigation, Writing–review & editing, CT: Investigation, Writing–review & editing, YM: Conceptualization, Methodology, Writing–review & editing.

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Figures:

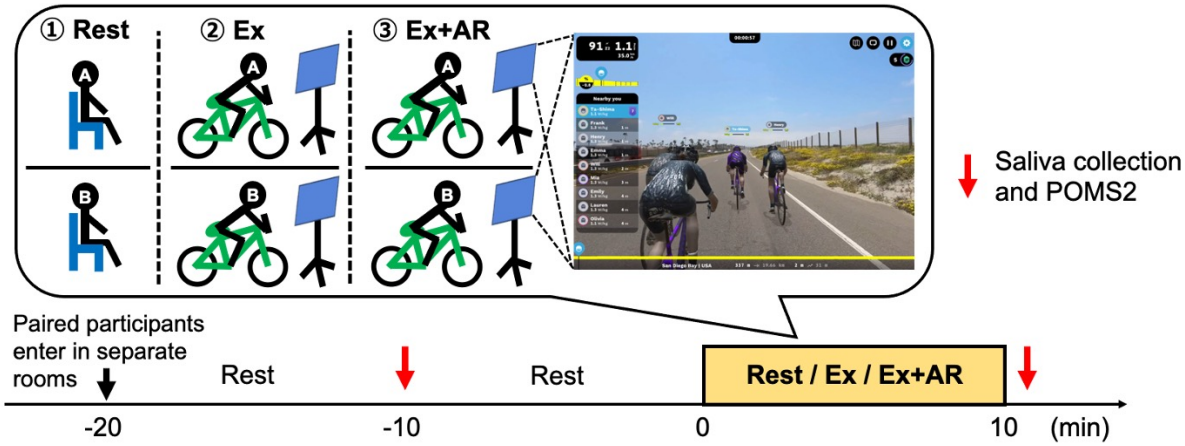


Fig. 1

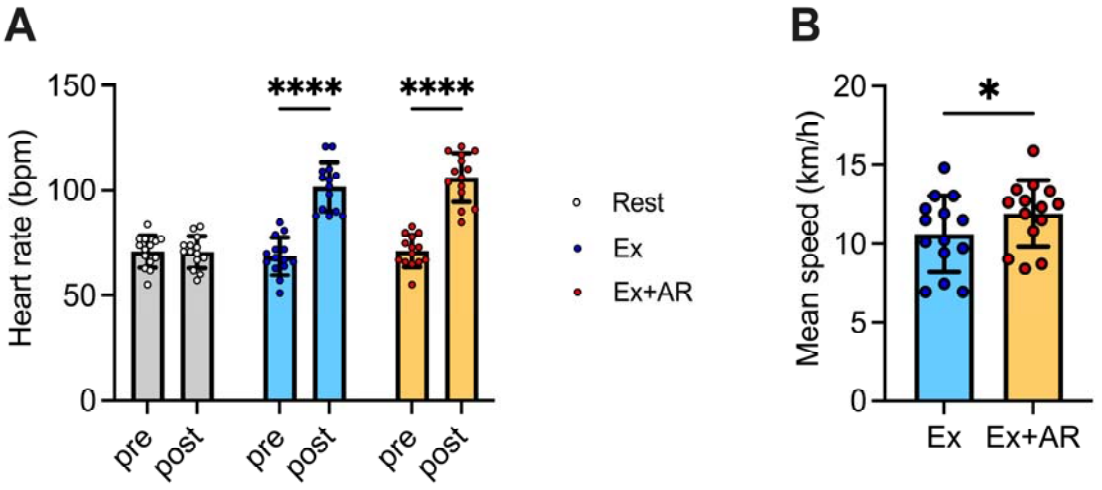

A
Heart rate (bpm)
150
100
50
0
****
****
pre
post
pre
post
pre
post
Rest
Ex
Ex+AR
B
Mean speed (km/h)
20
15
10
5
0
*
Ex
Ex+AR

Fig. 2

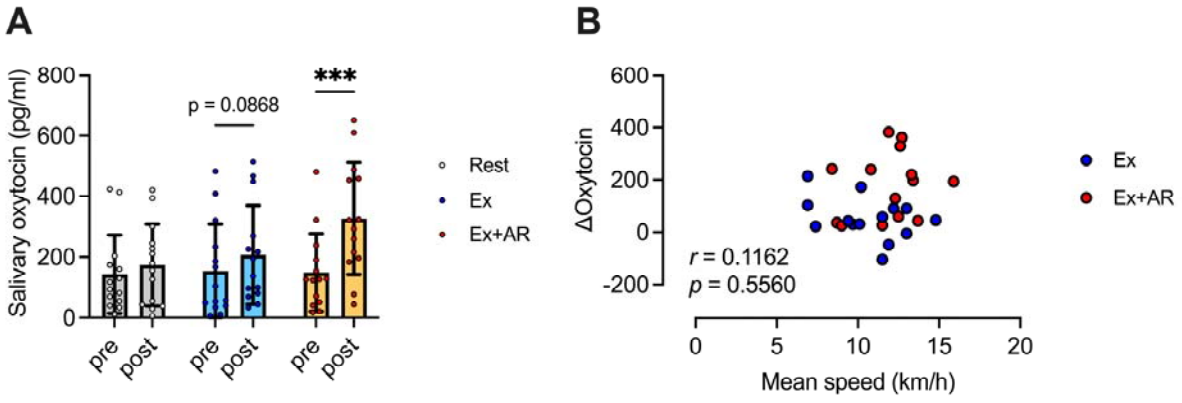
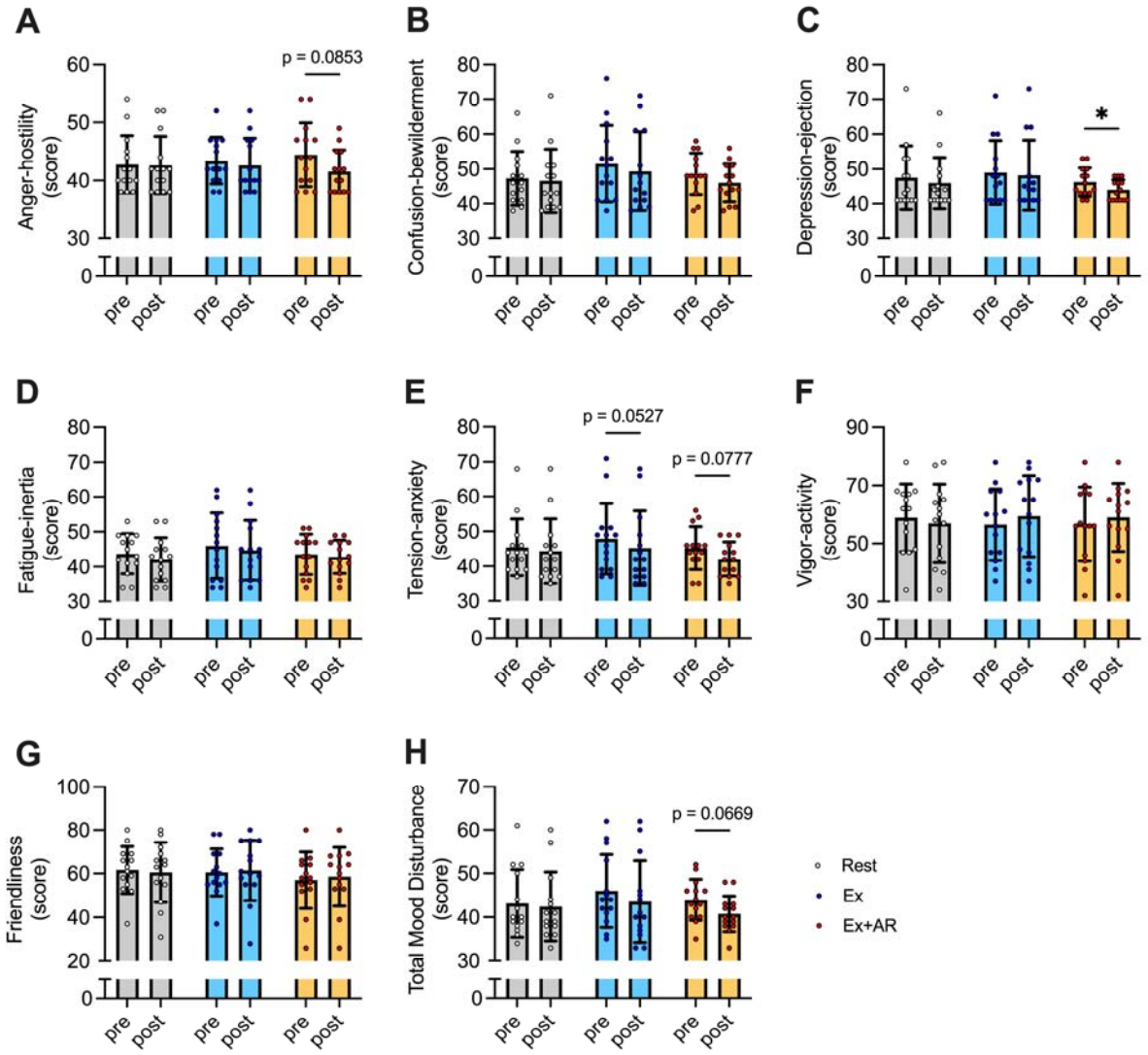

A
Salivary oxytocin (pg/ml)
800
600
400
200
0
p = 0.0868
***
pre
post
pre
post
pre
post
Rest
Ex
Ex+AR
B
ΔOxytocin
600
400
200
0
-200
r = 0.1162
p = 0.5560
0
5
10
15
20
Mean speed (km/h)
Ex
Ex+AR

Fig. 3


A
Anger-hostility (score)
p = 0.0853
B
Confusion-bewilderment (score)
C
Depression-ejection (score)
*
D
Fatigue-inertia (score)
E
Tension-anxiety (score)
p = 0.0527
p = 0.0777
F
Vigor-activity (score)
G
Friendliness (score)
H
Total Mood Disturbance (score)
p = 0.0669
pre
post
Rest
Ex
Ex+AR

411

412 **Fig. 4**

Figure legends:

Fig. 1. Experimental protocol in the current study.

Fig. 2. (A) The changes of heart rate in each condition. (B) The difference of mean cycling speed between Ex and Ex+AR condition. Ex: standard exercise condition, Ex+AR: augmented-reality-based exercise. Data are expressed as mean ± SD. Plots represent individual data, n = 14. $^{*}p < 0.05$, $^{****}p < 0.0001$.

Fig. 3. (A) The changes of salivary oxytocin levels in each condition. Ex: standard exercise condition, Ex+AR: augmented-reality-based exercise. Data are expressed as mean ± SD. Plots represent individual data, n = 14. $^{***}p < 0.001$. (B) The correlations between cycling speeds and exercise-induced changes in salivary oxytocin levels (ΔOxytocin).

Fig. 4. The changes of (A) anger-hostility, (B) confusion-bewilderment, (C) depression-ejection, (D) fatigue-inertia, (E) tension-anxiety, (F) vigor-activity, (G) friendliness and (H) total mood disturbance in each condition. Ex: standard exercise condition, Ex+AR: augmented-reality-based exercise. Data are expressed as mean ± SD. Plots represent individual data, n = 14. $^{*}p < 0.05$.