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# Beyond Rubik: The Embodiment–Presence–Interactivity Cube Applied to Exercise

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**Abstract**

Evidence-based interventions are needed to promote engagement in physical activity. Audio-visual stimuli are frequently employed to enhance the exercise experience. Nonetheless, there is a paucity of research that examines the qualities of technological devices that are employed. Using the Embodiment–Presence–Interactivity Cube (Flavián et al., 2019) as a guiding conceptual framework, the aim of this registered report was to examine how each dimension of the cube (i.e., embodiment, presence and interactivity) influenced a range of exercise-related affective and perceptual variables. A counterbalanced within-subjects design was employed ($N = 24$). Participants completed 20-min exercise bouts on a cycle ergometer under four conditions: Television, augmented reality, 360° video and virtual reality. A repeated-measures ANOVA indicated a significant Condition × Timepoint interaction for affective valence ($p = .046$), with greater embodiment offered by technological devices leading to more positive responses. Analyses also indicated main effects of condition for exercise enjoyment, remembered pleasure and forecasted pleasure, with greater presence of technological devices leading to more positive responses. Technologies that combine high levels of embodiment, presence and interactivity (e.g., virtual reality) appear to yield several benefits in terms of in-task (e.g., affective valence) and post-task (e.g., remembered pleasure) responses for exercise conducted at ventilatory threshold.

**Keywords:** affective valence, augmented reality, extended reality, immersion, immersive videos, virtual reality.

## Introduction

Sustained engagement in physical activity can help in the prevention and management of several non-communicable diseases, such as diabetes, heart disease and some cancers (Santos et al., 2023). Despite the evidence supporting the benefits of physical activity, there is a high incidence of physical inactivity and sedentary behaviour globally (Schultchen et al., 2019), and this has been exacerbated by the COVID–19 pandemic (Haseler & Haseler, 2022; Karageorghis, Bird, et al., 2021). Accordingly, there is a need for evidence-based interventions to promote engagement in regular physical activity among the general population (Stevens et al., 2020).

Interventions designed to promote physical activity typically target cognitive constructs (e.g., self-efficacy), but it is increasingly recognised that such interventions have only relatively small effects on behaviour (Ekkekakis et al., 2021; Rhodes et al., 2021). A plausible reason for this is that the social cognitive theories that have held sway over the last 40 years view individuals as fully rational beings, but generally disregard the role of affective phenomena (Ekkekakis et al., 2021). Consequently, researchers are beginning to acknowledge that affective constructs can help in bridging the gap between intention and behaviour (Stevens et al., 2020). Such constructs also provide a foundation for related physical activity and health-related interventions (Jones & Zenko, 2021).

### Exercise-Related Core Affect

There is considerable ambiguity surrounding affect-related constructs (Ekkekakis, 2013). The present investigation is oriented towards *core affect*, which can be defined as a "neurophysiological state, accessible to consciousness as a simple non-reflective feeling" (Russell, 2009, p. 1264). In accord with the Circumplex Model of Affect (Russell, 1980), core affect is conceptualised as a dimensional domain consisting of affective valence (ranging from *displeasure* to *pleasure*) and arousal (ranging from *low* to *high*). Psychological hedonism supports the notion that individuals pursue pleasure and avoid displeasure (Kahneman, 1999; Stevens et al., 2020), and there is evidence to suggest that such pleasure experienced during exercise is predictive of future behaviour (Rhodes & Kates, 2015; Williams et al., 2012). By means of illustration, Liao et al. (2017) found that a one-unit gain in negatively valenced affect reported during physical activity was associated with a decrease of 18.11 min of moderate-to-vigorous physical activity per day after 12 months. *Remembered pleasure* (i.e., how pleasant or unpleasant an event is remembered) and *forecasted pleasure* (i.e., how pleasant or unpleasant future events are anticipated to be) are also important in determining future exercise behaviour (Stevens et al., 2020). Researchers have, accordingly, attempted to create pleasurable exercise experiences to enhance the likelihood of sustained participation (Bird et al., 2021; Jones & Zenko, 2023).

The Dual-Mode Theory (DMT; Ekkekakis, 2003) addresses the relationship between exercise intensity and affective valence. The theory defines exercise intensity according to key metabolic markers, such as the gas-exchange ventilatory threshold (VT) and respiratory compensation point (RCP). Additionally, the DMT holds that, during exercise, affective valence is influenced by a combination of cognitive factors (e.g., appraisals, goals) and interoceptive cues (e.g., elevated heart rate, raised temperature). According to the DMT, affective valence below VT is primarily driven by cognitive factors and mostly positive among healthy individuals. Exercise intensities between VT and RCP are characterised by inter-individual variability, with some individuals reporting improvements, and others declines in affective valence. There is a universal decline in affective valence at intensities beyond the RCP, as interoceptive cues gain salience and physiological steady state cannot be maintained (Ekkekakis et al., 2020). Moreover, a rapid rebound towards pleasure is expected to occur following the cessation of strenuous exercise that induces a decrease in affective valence (Ekkekakis, 2013).

**Audio-Visual Technology**

A cost-effective intervention designed to enhance core affect during exercise concerns the use of technology to deliver audio-visual stimuli. This has been described as an *extrinsic* strategy, as it concerns manipulation of the exercise environment, as opposed to an *intrinsic* strategy, which targets components of exercise prescription (i.e., frequency, intensity, time and type; Jones & Zenko, 2021). Audio-visual stimuli are often used to promote *attentional dissociation*, which refers to the way in which the stimuli can guide attention outwardly. Dissociation, therefore, is a means by which attention can be directed away from the unpleasant sensations often associated with exercise (e.g., breathlessness, fatigue and muscular pain; Bird et al., 2019).

The Embodiment–Presence–Interactivity (EPI) Cube (Flavián et al., 2019) is a contemporary framework that categorises technological devices according to three dimensions (see Figure 1). *Embodiment* concerns the degree of integration between a technological device and the human body. External devices (e.g., portable Bluetooth speakers) are associated with low embodiment, as they are not integrated with the human body. Conversely, internal devices (e.g., headphones) are associated with high embodiment, as they are fitted to an individual user. Internal devices were posited to confer greater technological immersion (i.e., supporting natural sensorimotor contingencies for perception; Slater, 2018) when compared to external devices (Flavián et al., 2019).

*Presence* refers to the sense of being transported to another environment (Slater, 2018). It is noteworthy that technological immersion is considered an antecedent of presence (Harris et al., 2020). Hence, internal devices that comprise high technological immersion (e.g., virtual reality [VR] headsets) have been theorised to elicit greater perceptions of presence when compared to external devices (Flavián et al., 2019). Finally, *interactivity* is a behavioural factor pertaining to the extent to which users can control and manipulate the virtual environment that is presented to them. The EPI Cube might serve to further understanding of how technology facilitates positive exercise-related core affect and is thus used to guide the present investigation.

***** Insert Figure 1 here *****

## Music Applications in Exercise

Researchers have demonstrated that music can enhance exercise-related affect across several modalities, including walking (Pottratz et al., 2021), running (Hutchinson et al., 2018) and cycle ergometry (Bird et al., 2016). Furthermore, a meta-analysis indicated that music's influence on affective responses is the largest ($g$ = 0.48) among several exercise-related outcome variables (e.g., perceived exertion, oxygen consumption; Terry et al., 2020). Close inspection of the technologies employed to deliver music-related interventions reveals that they fall broadly along the *z*-axis of the EPI Cube (see Figure 1; Flavián et al., 2019). For example, external speakers (e.g., Karageorghis, Jones, et al., 2021) are considered to comprise low embodiment whereas bone-conduction headphones (e.g., Aburto-Corona et al., 2023) are more integrated with the individual exerciser. Nonetheless, such devices are, by design, limited in terms of how they elicit presence and behavioural interactivity.

## Audio-Visual Applications in Exercise

Researchers have also integrated a range of audio-visual stimuli within the exercise environment, such as music-videos (Pottratz et al., 2021), sporting highlights (Barwood et al., 2009) and film scenes (Bigliassi et al., 2019). This represents a shift in focus towards technologies that fall along the *y*-axis of the EPI Cube (see Figure 1; Flavián et al., 2019), albeit exercisers' perceptions of presence are rarely measured by investigators (Chow & Etnier, 2017). An oft-cited rationale for employing auditory and visual stimuli concurrently is that plural stimuli (e.g., music-video) *should* be superior to a singular stimulus (e.g., music) in terms of promoting attentional dissociation and engendering more positive exercise-related affect (Hutchinson et al., 2017; Jones et al., 2014).

The evidence surrounding this intuitive prediction appears inconclusive. For example, Bird et al. (2019) reported that 360° videos without sound (i.e., a singular stimulus) facilitated greater attentional dissociation and higher affective valence scores during cycle ergometry at the VT when compared to a music-video condition (i.e., plural stimuli). The 360° videos were delivered by use of a VR headset, while the music-videos were shown on a laptop. Hence, there is a need to not only consider the nature of audio-visual stimuli that exercisers are subjected to, but also the qualities of the technological devices used to deliver them. The EPI Cube (Flavián et al., 2019) holds that 360° videos prompt greater perceptions of presence and embodiment when compared to traditional displays and this framework might help in accounting for the findings reported by Bird et al. (2019).

**Interactive Audio-Visual Applications in Exercise**

Interactive technologies are progressively being implemented within exercise contexts and this represents a shift towards technologies that fall along the *x*-axis of the EPI Cube (Flavián et al., 2019). For example, researchers have used VR to accompany isometric strength tasks and reported lower pain ratings and longer times-to-exhaustion when compared to a control condition (Matsangidou et al., 2019). Likewise, Kocur et al. (2020) examined the effects of VR avatars and found that muscular avatars prompted lower ratings of perceived exertion (RPE) when compared to medium and non-muscular avatars.

VR has also been used during aerobic exercise protocols, such as cycle ergometry. Zeng et al. (2017) reported that a VR condition was associated with lower RPE, higher self-efficacy and greater enjoyment when compared to a non-VR condition. Similarly, Bird et al. (2021) found that VR elicited more positive affective valence, higher arousal, greater attentional dissociation and more enjoyment during cycle ergometry at 10% below VT when compared to a music-only condition. The researchers argued that greater perceptions of presence in the VR condition were responsible for these findings. However, this was not measured in relation to each experimental condition. Moreover, the degree to which embodiment (i.e., internal devices used in the VR condition vs. external devices used in the music condition) mediated the findings remains unknown and is thus worthy of research attention.

**Aims and Hypotheses**

There is a pressing need to develop evidence-based interventions that target affective components of the exercise experience (Stevens et al., 2020). Audio-visual stimuli are almost ubiquitous in exercise settings and researchers have demonstrated their effectiveness in prompting dissociative thoughts and enhancing exercise-related affect (Bird & Karageorghis, 2020; Jones et al., 2014). It has been suggested that plural stimuli should prompt greater attentional dissociation when compared to a singular stimulus (Hutchinson et al., 2017). However, a limitation of this prediction is that it does not acknowledge the qualities of the technological devices used for the delivery of such stimuli. Accordingly, the use of theoretical frameworks that can differentiate among a range of available technologies is warranted. This is likely to further understanding of the effects of audio-visual stimuli in exercise and health contexts.

Employing the EPI Cube (Flavián et al., 2019) as a guiding conceptual framework, the aim of the investigation was to examine the extent to which three technological qualities (i.e., embodiment, presence and interactivity) influence affective and perceptual variables during exercise. To address this aim, four technological devices were used to display exercise-congruent visual stimuli accompanied by music: Television (TV; low embodiment, presence and interactivity), augmented reality (AR; high embodiment, low presence and interactivity), 360° video (high embodiment and presence, low interactivity) and VR (high embodiment, presence and interactivity; see Figure 1). These technologies were selected as they are gaining increased popularity within exercise facilities (Bird & Karageorghis, 2020; Jones & Ekkekakis, 2019). Exercise was performed at the VT, as this intensity falls within a zone that is associated with the greatest inter-individual variability in affect (Ekkekakis, 2003; Ekkekakis et al., 2020).

It is hypothesised that devices with higher values of embodiment, presence and interactivity will prompt more positive affective valence ($H_1$), greater attentional dissociation and reduced RPE ($H_2$), as well as higher exercise enjoyment, remembered pleasure and forecasted pleasure ($H_3$). Moreover, it is hypothesised that the TV condition (low embodiment, presence and interactivity) will elicit the most pronounced affective rebound (i.e., rise in affective valence upon cessation of exercise), owing to expected higher affective valence scores during exercise in each of the three remaining conditions ($H_4$). Finally, with reference to an outcome-neutral test, it is hypothesised that the arousal dimension of core affect will be statistically equivalent across conditions ($H_5$).

# Method

## Participants

A simulation-based power analysis was conducted in RStudio (v. 2022.07.1) with the Superpower package in accord with recommendations for factorial designs (Lakens & Caldwell, 2021). The extant literature (Bird et al., 2019, 2021) was drawn upon to inform the predicted pattern of means for affective valence across conditions. A power curve indicated that 20 participants would be required to obtain 90% power in relation to a 4 (Condition) × 4 (Time) interaction effect and the associated Quarto markdown file can be located online (https://osf.io/47aue/).

The investigation was approved by the University of Exeter Research Ethics Committee (200325/A/05). Recruitment was conducted through word-of-mouth and promotional posters/flyers at the University and posts on social media platforms. Inclusion criteria stipulated that participants were: (a) between 18–30 years of age, (b) recreationally active according to the Physical Activity Readiness Questionnaire (Warburton et al., 2011), (c) without any visual impairment and/or hearing deficiency and (d) familiar with cycle ergometry. Individuals were pre-screened for susceptibility to motion sickness by means of the Visually Induced Motion Sickness Susceptibility Questionnaire (VIMSSQ; Golding et al., 2021). Twenty-four adult volunteers were recruited to facilitate a fully counterbalanced design ($N_{female}$ = 13, $M_{\text{age}}$ = 26.21, $SD_{\text{age}}$ = 3.05 years, $M_{\text{BMI}}$ = 22.50, $SD_{\text{BMI}}$ = 3.14 kg/m$^2$).

**Experimental Procedures**

The procedures detailed herein build upon a corpus of experimental studies published by the research team (Bird et al., 2019, 2021; Jones & Wheat, 2023). Participants were invited to visit the laboratory on three occasions (i.e., one habituation/incremental exercise test and two experimental sessions; see Supplementary Material 1). During habituation, each participant completed the PAR-Q (Warburton et al., 2011), VIMSSQ (Golding et al., 2021) and a short demographic questionnaire. The experimenter recorded each participant's height and weight before explaining each of the measures that would be used in the experimental trials. Each participant was shown how to correctly fit and adjust the headsets used to administer the audio-visual stimuli in the AR, 360° video and VR conditions. Thereafter, they were required to complete an incremental exercise test on an electronically braked cycle ergometer (Lode Corival cpet, Groningen, NL) so that their VT could be ascertained (Bird et al., 2021; see Supplementary Material 2).

A fully counterbalanced within-subjects design was employed and the first tranche of experimental testing took place at least 48 hr after the initial habituation session. Each participant was instructed to have adequate sleep the night before experimental sessions, to avoid alcohol consumption and to refrain from ingesting caffeine on the day of the testing.

The investigation entailed administration of an exercise bout under four conditions, each of which was associated with a distinct vertex of the EPI Cube (Flavián et al., 2019): TV (Vertex 1), AR (Vertex 5), 360° video (Vertex 7) and VR (Vertex 8). These specific technologies enabled the construction of repeated planned contrasts (see Figure 1), in accord with $H_{1–3}$. All conditions were accompanied by experimenter-selected music at a standardised intensity of ~70 dBA. The music was administered via an external speaker in the TV condition and by use of wearable, bone conduction headphones in the AR, 360° and VR conditions. This ensured compatibility across the devices used to administer the auditory and visual stimuli in terms of the embodiment dimension of the EPI Cube (Flavián et al., 2019).

Each trial lasted for 20 min with the participant required to complete a 2.5 min warm-up at 20% below VT, 15 min exercise at VT and 2.5 warm-down at 20% below VT on a cycle ergometer (see Supplementary Material 1). Each participant was instructed to maintain a cadence of 75 ± 3 rpm throughout each trial and the experimental manipulation coincided with the 15-min exercise phase (Bird et al., 2021; see Figure 2). The participant completed two trials during each laboratory visit and recovery periods of 15 min were administered in between trials to allow heart rate to descend to resting values. Full details of the audio-visual selection procedure can be located in Supplementary Material 3.

***** Insert Figure 2 here *****

**Measures**

In-task measures of core affect were administered throughout each trial at baseline and after 1, 4, 8, 12, 16 and 19 min to capture the dynamic nature of exercise-related affect (Ekkekakis et al., 2020). However, data obtained at baseline and during the warm-up (i.e., after 1 min) and warm-down (i.e., after 19 min) were not subject to statistical analysis in relation to $H_{1–2}$, as these timepoints did not coincide with the experimental manipulation.

Baseline data were only intended for analytical purposes (i.e., as covariates) in the event that significant ($p < .05$) pre-task differences emerged in core affect across conditions.

Given that core affect was conceptualised as a dimensional domain, affective valence was assessed using the Feeling Scale (FS; Hardy & Rejeski, 1989) and arousal using the Felt Arousal Scale (FAS; Svebak & Murgatroyd, 1985). The FS is a single-item, 11-point scale anchored by -5 (*[I feel] very bad*) and 5 (*very good*). The FAS is a single-item, six-point scale anchored by 1 (*low arousal*) and 6 (*high arousal*). In-task perceptual measures were administered during the main exercise phase, after 4, 8, 12 and 16 min. RPE was assessed using the Borg CR10 Scale (Borg, 1998), which is anchored by 0 (*nothing at all*) and 10 (*extremely strong*). State attentional focus was measured using the Attentional Scale (AS; Tammen, 1996), which is anchored by 0 (*internal focus* [bodily sensations, heart rate, breathing, etc.]) and 100 (*external focus* [daydreaming, external environment, etc.]).

Following the cessation of each trial, exercise enjoyment was assessed using the Physical Activity Enjoyment Scale (PACES; Kendzierski & DeCarlo, 1991), which is comprised of 18 items attached to 7-point scales (e.g., 1 = *I enjoy it*, 7 = *I hate it* [item 1]). Remembered pleasure was measured using a visual analogue scale attached to the question "How did the exercise session make you feel?" The scale ranges from -100 (*very unpleasant*) to 100 (*very pleasant*) in intervals of 1. A slider was positioned at the origin (0) but the numbers were not visible to participants (Zenko et al., 2016). Forecasted pleasure was assessed by means of the Empirical Valence Scale (Lishner et al., 2008). Each participant was required to respond to the question "If you repeated the exercise session again, how do you think it would make you feel?" (Zenko et al., 2016). Fifteen empirically spaced verbal descriptors are depicted underneath the scale, ranging from -100 (*most unpleasant imaginable*) to 100 (*most pleasant imaginable*). The values were hidden from participants, who were instructed to select one descriptor only. As a manipulation check, perceptions of presence were measured using the Spatial Presence Experience Scale (SPES; Hartmann et al., 2016), which comprises eight items attached to a 5-point scale anchored by 1 (*I do not agree at all*) and 5 (*I fully agree*).

**Data Analysis**

The analysis plan was pre-registered via the Open Science Framework (https://osf.io/47aue/) and all analyses were conducted in RStudio (v. 2023.09.1). Initially, data were screened for univariate outliers using $z$-scores ($z \pm 3.29$). Outliers were treated by adjusting the raw score by one unit smaller or larger than the next most extreme score in the distribution until $z < \pm 3.29$ (Tabachnick & Fidell, 2019). Checks were made for the parametric assumptions underlying repeated-measures (RM) ANOVA. For example, the distributional properties of the data were examined visually by means of Q–Q plots and histograms (Coolican, 2018).

The valence dimension of core affect and perceptual variables (RPE and attentional focus) were assessed using factorial 4 (Condition) × 4 (Time) RM ANOVAs. Exercise enjoyment, remembered pleasure, forecasted pleasure and presence were analysed by means of one-way RM ANOVAs. The magnitude of affective (valence) rebounds was assessed by means of a factorial 4 (Condition) × 2 (Time) RM ANOVA. The arousal dimension of core affect was subjected to two one-sided tests (TOSTs), as a means by which to determine statistical equivalence across conditions. Greenhouse–Geisser adjustments were made to $F$ tests in which the sphericity assumption was violated. Three repeated contrasts were used to examine the influence of embodiment (TV vs. AR), presence (AR vs. 360° video) and interactivity (360° video vs. VR) of technological devices on the dependent variables in relation to $H_{1–3}$. In the case of possible Condition × Timepoint interaction effects pertaining to affective valence and perceptual variables, such contrasts only applied to the final timepoint within the main exercise task (i.e., after 16 min). Planned contrasts were subject to

Holm–Bonferroni adjustment, given that they were non-orthogonal (Field et al., 2012). Data and analysis scripts can be located online (https://osf.io/47aue/).

## Results

Data screening revealed nine univariate outliers (z > ± 3.29) pertaining to affective valence (*n* = 1), exercise enjoyment (*n* = 2) and presence (*n* = 6) scores. In all instances, outliers were treated by adjusting the raw score by one unit smaller or larger than the next most extreme score in the distribution until $z < \pm 3.29$ (Tabachnick & Fidell, 2019). Tests of the distributional properties of the data indicated violations of normality in 15 cells of the analysis (nine at $p < .05$, four at $p < .01$ and two at $p < .001$). We did not transform these data given concerns regarding the transformation of data derived from Likert scales (see Nevill & Lane, 2007).

### Core Affect

A one-way RM ANOVA on affective valence indicated a non-significant main effect of condition at baseline ($p = .751$, $\eta_p^2 = .02$) and hence these data were not subsequently used as a covariate. A factorial RM ANOVA indicated a significant 4 (Condition) × 4 (Timepoint) interaction for affective valence during the main exercise phase ($p = .046$, $\eta_p^2 = .08$; see Table 1). Greater embodiment of technological devices was associated with enhanced affective valence during the final timepoint of the exercise bout (i.e., 16 min), reflected in the statistically significant difference between the TV and AR conditions ($p = .019$, 95% CI [0.09, 1.24]; see Figure 3).

***** Insert Figure 3 here *****

A factorial RM ANOVA indicated a significant 4 (Condition) × 2 (Timepoint) interaction effect pertaining to affective valence scores at the final timepoint during the main exercise period (i.e., 16 min) and during cool-down (i.e., 19 min; $p = .017$, $\eta_p^2 = .14$; see Table 1). Pairwise comparisons indicated a significant improvement in affective valence scores in the TV condition only ($p$ = .029, 95% CI [0.04, 0.63]). It is noteworthy that all remaining conditions were associated with declines in affective valence scores at 19 min during the cool-down, despite a reduction in exercise intensity (see Figure 4).

***** Insert Figure 4 here *****

The TOST procedure indicated statistical equivalence between the 360° video and VR conditions for affective arousal during the final timepoint of the main exercise bout, $t(23) = -3.50$, $p < .001$. However, statistical equivalence was not demonstrated between AR and 360° video $t(23) = .96$, $p = .174$, nor between TV and AR conditions, $t(23) = 1.45$, $p = .080$.

**Perceptual Variables**

The RPE analysis indicated that the 4 (Condition) × 4 (Timepoint) interaction was non-significant ($p = .588$, $\eta_p^2 = .03$; see Supplementary Material 4). There was, however, a main effect of time ($p < .001$, $\eta_p^2 = .62$). Pairwise comparisons indicated lower RPE scores after 4 min when compared to 8 min ($p$ < .001, 95% CI [-0.84, -0.28]), 12 min ($p$ < .001, 95% CI [-1.35, -0.43]) and 16 min ($p$ < .001, 95% CI [-1.75, -0.76]). The state attention analysis indicated that the 4 (Condition) × 4 (Timepoint) interaction was non-significant ($p = .069$, $\eta_p^2 = .09$; see Supplementary Material 4). There was, however, a significant main effect of condition ($p < .001$, $\eta_p^2 = .29$), albeit that the Holm–Bonferroni adjustment caused the embodiment contrast to be non-significant ($p > .05$).

**Post-Task Psychological Measures**

A one-way RM ANOVA for exercise enjoyment (derived from PACES) indicated a significant main effect of condition ($p < .001$, $\eta_p^2 = .53$). Greater embodiment (TV vs. AR), presence (AR vs. 360° video) and interactivity (360° video vs. VR) of technological devices were all associated with higher enjoyment scores ($p$ = .024, 95% CI [0.32, 18.35]; $p$ = .024, 95% CI [1.40, 23.52]; $p$ = .024, 95% CI [0.63, 14.54], respectively; see Figure 5a).

***** Insert Figure 5 here *****

A one-way RM ANOVA for remembered pleasure indicated a significant main effect of condition ($p < .001$, $\eta_p^2 = .44$). Greater presence of technological devices was associated with higher scores for remembered pleasure ($p = .038$, 95% CI [1.04, 44.46]). Similarly, greater interactivity of technological devices was associated with higher scores for remembered pleasure ($p = .043$, 95% CI [-0.71, 31.46]; see Figure 5b). A one-way RM ANOVA for forecasted pleasure indicated a significant main effect of condition ($p < .001$, $\eta_p^2 = .47$). Planned contrasts indicated that only the presence dimension of the EPI Cube was associated with greater scores for forecasted pleasure (i.e., AR vs. 360° video; $p = .005$, 95% CI [5.86, 37.05]; see Figure 5c).

A one-way RM ANOVA for presence scores indicated a significant main effect of condition ($p < .001$, $\eta_p^2 = .76$). All three planned contrasts were significant, but a clear step change was evident between the AR and 360° video conditions ($p < .001$, 95% CI [5.70, 15.72]; see Supplementary Material 4).

## Discussion

The purpose of the present study was to examine the degree to which the three technological qualities of embodiment, presence and interactivity influence affective and perceptual variables during exercise at VT. Flavián et al.'s (2019) EPI Cube provided a guiding conceptual framework, from which five research hypotheses were derived. The results from the investigation led to acceptance, non-acceptance and partial acceptance of the hypotheses, each of which will be considered henceforth.

$H_1$ held that devices characterised by higher values of embodiment, presence and interactivity would prompt higher scores for affective valence. This hypothesis is only partially accepted, given that greater embodiment elicited more positive affective valence, but not so in the case of presence and interactivity (see Figure 3). Along similar lines, $H_2$ held that high embodiment, presence and interactivity would engender greater attentional dissociation, coupled with lower RPE scores. This hypothesis was not accepted, given that the 4 (Condition) × 4 (Timepoint) interactions for both state attention and RPE were non-significant (*p*s > .05).

$H_3$ predicted that high embodiment, presence and interactivity would lead to higher exercise enjoyment, remembered pleasure and forecasted pleasure. Given the significant main effects (all at $p < .001$) that emerged for these three variables (see Figure 5), this hypothesis is accepted. $H_4$ predicted that the TV condition would exhibit the most pronounced affective rebound. Given the significant ($p = .017$) 4 (Condition) × 2 (Timepoint) interaction for affective valence and the clear pattern of change evident (see Figure 4), this hypothesis is also accepted. Finally, $H_5$ – associated with the outcome-neutral test – was predicated on the notion that affective arousal would be statistically equivalent across conditions. This hypothesis was not accepted given that the TOST procedure indicated a lack of equivalence between AR and 360° video, as well as between TV and AR conditions.

**Core Affect**

Although greater embodiment elicited more positive affective valence, it is evident that presence and interactivity did not. The partial acceptance of $H_1$ highlights a need to examine why presence and interactivity did not enhance the pleasure that participants experienced during the exercise (see Figure 3). It is conceivable that significant differences for the presence and interactivity contrasts would have emerged with a slightly longer exercise protocol. However, it is necessary for researchers to be mindful of simulator sickness when considering lengthy protocols that involve use of immersive technologies (Bird, 2020). It is noteworthy that VR appears to engender *much* greater pleasure than TV and AR. Hence, it is plausible that the combination of high presence and high interactivity are germane to the modulation of exercise-related affect (cf. Bird et al., 2021; Jones & Wheat, 2023).

In relation to $H_4$, the affective rebound evident in the TV condition, but not in any other condition (see Figure 4), can be understood with reference to the pattern of affective valence responses during exercise at VT (see Figure 3). Specifically, there was affective decline evident throughout the exercise bout in the TV condition and, by comparison, fairly even trendlines in the other three conditions over time. The affective decline in the TV condition was followed by a rebound during the period of active recovery at 20% below VT. From a theoretical standpoint, the technological qualities that characterise AR, 360° video and VR (see Flavián et al., 2019) contributed towards the enhancement of affective valence to such a degree, that there was little scope for a rebound during active recovery (cf. Bird et al., 2021). When the exercise experience is unpleasant, a rapid increase in pleasure is observed following its cessation (Ekkekakis, 2013; Ekkekakis et al., 2011).

The outcome-neutral test ($H_5$) yielded an unexpected result. Notably, 360° video and VR conditions exhibited comparable levels of affective arousal, but there was a lack of equivalence given the lower levels associated with AR and TV, respectively. It is noteworthy that this pattern of scores tessellates with that for presence, with a step change from TV and AR, to 360° video and VR. Hence, the increased perception of presence afforded by 360° videos and VR, both of which fully occlude the user's physical reality, could have upregulated affective arousal in these conditions. The higher levels of affective arousal in AR relative to TV might be accounted for by the level of embodiment afforded by the head-mounted AR device, which requires more active attention, with an attendant small increase in arousal to enable this. Another possibility is a novelty effect, given that head-mounted AR is the most recent technology employed in the present investigation (see Bird et al., 2023). Collectively, the results of the outcome-neutral test suggest that the variable of affective arousal was not a good choice in this regard, albeit previous literature suggested it might be (Bigliassi et al., 2019; Bird et al., 2016).

**Perceptual Variables**

Findings for the perceptual variables did not provide support for the associated hypothesis ($H_2$), given the absence of significant 4 (Condition) × 4 (Timepoint) interactions for both RPE and state attention. There was a main effect of time for RPE with a pronounced increase in scores over time. This finding, however, is not of interest from a theoretical standpoint, given that RPE is fully expected to rise in a stepwise motion during a 15-min exercise bout at VT (see e.g., Alvarez-Alvarado et al., 2019). The lack of a main effect of condition hints at the possibility that the inclusion of asynchronous music as an adjunct to the visual stimuli may have overridden the dissociative effects of the embodiment–presence–interactivity manipulation (Hutchinson et al., 2017; Hutchinson & Karageorghis, 2013). Notably, in contrast to most related studies (Bird et al., 2019; Jones et al., 2014), *only* plural stimuli were administered in the present study. This was done with a view to (a) keeping the focus on the three technological qualities germane to the EPI Cube (including use of a different mode of music delivery in the TV condition [external speaker] to ensure low embodiment) and (b) maintaining a degree of external validity given the ubiquity of music in exercise settings (Terry et al., 2020).

The significant main effect of condition indicates increasing levels of dissociation (i.e., higher state attention scores) sequentially from the TV through to the VR condition. Although RPE was not influenced by condition, the fact that state attention was, suggests that the increase in dissociation afforded by high embodiment and presence (360° video and VR) did not manifest in lower perceived exertion. RPE and state attention are not phenomenologically isomorphic (Razon et al., 2009), therefore we might speculate that different neural circuits are implicated in the self-assessment of these constructs; a topic that warrants investigation from a neurophysiological perspective (e.g., by means of coherence analyses using electroencephalography; see Bigliassi et al., 2017).

Using extant theory and empirical work to explore *why* higher levels of embodiment and presence led to an increase in dissociation but not a reduction in RPE, we might draw upon the work of Alvarez-Alvarado et al. (2019). In developing their inclusive model on the interplay between workload and functional perceptual–cognitive–affective responses, these authors assessed attentional focus and RPE during an incremental cycle ergometer test to volitional exhaustion. The linear trendlines for attentional focus and RPE were identical, and notably, their test was conducted in a sterile laboratory environment. The inclusion of technological aids, such as VR, appears to engender a differential trend in these closely related perceptual variables. It is plausible that at VT, the combination of high levels of embodiment and presence change how attention is directed (primarily a cognitive process), but have little bearing on subjective perception of effort (primarily a sensory process; see Razon et al., 2009).

**Post-Task Psychological Measures**

The post-task measures exhibited trends that were in accord with the associated research hypothesis ($H_3$; see Figure 5). From a theoretical perspective, the greater attentional demands placed by combinations of the three technological qualities, have an additive effect in terms of enhancing scores on the post-task measures (cf. Tenenbaum, 2001). Specifically, the way in which sensory modalities are tapped serves to direct attention away from internal, fatigue-related cues, and can lead to the experience of greater pleasure and enjoyment. From a mechanistic perspective, it has recently been demonstrated that immersive technologies (e.g., VR) reduce activation in the prefrontal cortex (Jones & Wheat, 2023). This is notable given that activation in this brain region is inversely related to affective responses during exercise (see also Jones & Ekkekakis, 2019). From a practical perspective, the stark differences that emerged in the post-task measures between TV – a commonly used form of entertainment in fitness facilities – when compared to 360° video and VR are noteworthy.

These findings add to a growing corpus of findings demonstrating the benefits of immersive technology in an exercise context (Bird et al., 2019; Jones & Ekkekakis, 2019; Jones & Wheat, 2023).

**Strengths and Limitations**

The present investigation was conducted in accord with the principles of Open Science (e.g., pre-registration, data availability), which is known to increase the integrity of the results (Hagger, 2022). The work was grounded in a conceptual framework (Flavián et al., 2019) that incorporated the qualities of each form of technology administered during the exercise task. This enabled the formulation of theoretically derived planned contrasts, advancing previous work, which typically used post-hoc tests that did not have a theoretical basis. Moreover, Ekkekakis's (2003) DMT served as a lodestar for the selection of an exercise intensity (VT) at which the experimental manipulations would be likely to engender a meaningful effect, due to expected inter-individual variability in exercise-related affect. Related to this, a further strength is that unlike many comparable studies (e.g., Pottratz et al., 2021; Zeng et al., 2017), the exercise intensity was calculated with reference to heart rate variability indices to ensure accuracy and minimise between-subject variability (see Supplementary Material 2).

The study included a manipulation check – an assessment of presence – that exhibited a trend broadly in line with expectations. The plurality of technologies through which visual stimuli were delivered represents a considerable advancement in terms of the evolution of this subset of the exercise psychology literature (see e.g., Bird et al., 2019, 2021; Pottratz et al., 2021). Exercisers and exercise practitioners can use the present data to gauge the psychological benefits that might be derived from a range of audio-visual technologies.

A limitation was that it was not feasible for the research team to include an intervention that represented each of the eight vertices of the EPI Cube (see Figure 1).

Nonetheless, some of the technologies associated with vertices not included in the present design (e.g., mixed reality headsets) have yet to reach a level of technological maturity to prompt wide-scale adoption. This means that their inclusion had the potential to undermine ecological validity, but also to engender a fatigue effect (Heath, 2018). A further limitation is that only one exercise intensity was tested (VT). It could be that higher intensities would have brought certain weaknesses to light in technologies that require coverage of the head (e.g., 360° video and VR) due to greater thermoregulation (Rupp, 2024). Conversely, use of a slightly lower intensity (e.g., 5% below VT) might have precipitated the expected differences in affective valence ($H_1$). Although the EPI Cube provides a useful lens through which to examine technological aids in the exercise context, there is presently a lack of theory that specifically addresses the differential effects of technological qualities on key affective and perceptual outcomes during exercise (cf. Jones & Wheat, 2023).

**Implications for Practice and Future Research**

A clear implication that is predicated on the present findings is that technologies that combine high levels of embodiment, presence and interactivity (e.g., VR) hold manifold benefits in terms of in-task (e.g., affective valence) and post-task (e.g., remembered pleasure) responses for exercise conducted at VT. Such exercise has the propensity to deliver a range of cardio-metabolic benefits (Santos et al., 2023), but is characterised by considerable variability in participants' affective responses (Ekkekakis, 2003; Ekkekakis et al., 2020). Technologies that offer high qualities in *any* of the EPI Cube dimensions or *any* of the two dimensions in combination, appear to assuage the in-task decline that is typically observed during exercise at VT (Jones & Ekkekakis, 2019; see Figure 3). Drawing also on previous findings (Bird et al., 2019), it is apparent that psychological benefits can be derived from plural (360° video with music) *and* singular stimuli (360° video).

As previously detailed, the selection of affective arousal for the outcome-neutral test, or “sanity check”, did not prove to be an entirely apposite choice. Future researchers who design experiments of a similar nature might consider use of a photoplethysmogram (attached to the ear lobe) to monitor non-cortical haemodynamic responses (i.e., extra-cerebral noise should be similar across conditions; see Guérin et al., 2023) or heart rate variability indices (e.g., root mean square of successive RR interval differences [RMSSD] and standard deviation of normal-to-normal RR intervals [SDNN]; Karageorghis et al., 2022). It seems from the present findings that affective arousal is sensitive to manipulations predicated on the three dimensions of the EPI Cube; particularly when high embodiment is combined with high presence.

There is scope for future researchers to test each of the eight vertices of the EPI Cube. Although from a logistical perspective this would be a challenging study given the level of commitment required from participants, with appropriate inducements to encourage repeat laboratory visits, this approach would extend the approach adopted in the present study (four vertices). Moreover, now that there are fully integrated systems for the delivery of VR alongside measurements of electrical activity in the brain (eletroencephalography [EEG]) and cerebral haemodynamics (functional near-infrared spectroscopy [*f*NIRS]), there are opportunities to study the neurophysiological mechanisms associated with exercise at varying levels of embodiment, presence and interactivity (e.g., the integrated VR–EEG–*f*NIRS system of MedelOpt, Seenel Imaging, Tourcoing, FR). Investigation of underlying mechanisms would further understanding of the exercise intensity-related “efficacy zones” associated with a range of audio-visual technologies (Karageorghis et al., 2017). Such work would also light a path towards theoretical advances that address how technological manipulations, and specifically the qualities of embodiment, presence, and interactivity, differentially influence affective and perceptual responses to exercise.

## Conclusions

The hypothesised two-way interaction effect of condition for affective valence ($H_1$) did not emerge precisely as expected, albeit the combination of high embodiment, presence and interactivity offered by VR elicited the most pleasurable exercise experience (see Figure 3). Also, cross-condition equivalence was expected for affective arousal ($H_5$), but the combination of high embodiment and presence (360° video and VR conditions) led to higher scores than the other combinations of EPI Cube dimensions that we tested (TV and AR). The findings for the affective rebound (see Figure 4) were in accord with our expectations ($H_4$), suggesting that *any* configuration of high values on the EPI dimensions (i.e., with one, two, or three dimensions) assuaged the affective decline that is typically observed during exercise at VT.

It is also the case that the perceptual measures (RPE and state attention) did not yield the pattern of results that we expected, leading to non-acceptance of $H_2$. The associated 4 (Condition) × 4 (Timepoint) interactions were non-significant, meaning that RPE and state attention did not change as expected in the epoch 4–16 min. It seems, accordingly, that although the combination of high levels of embodiment, presence and interactivity did not have a bearing on *what* participants felt, it did influence *how* they felt it (cf. Hardy & Rejeski, 1989). The practical implication is that technologies such as VR and 360° video can serve to "colour" the interpretation of fatigue during exercise at VT. Moreover, the present findings support previous empirical work indicating that measures of RPE and state attention are not phenomenologically isomorphic (see Razon et al., 2009).

Post-task measures of exercise enjoyment and remembered/forecasted pleasure provided compelling evidence that technologies associated with the greatest presence (i.e., VR and 360° video) elicited the most positive scores. Each of the associated effect sizes was large ($\eta_p^2$ range: .44–.53). There is an emerging body of neurophysiological work that provides a mechanistic basis for the findings we observed in terms of post-task measures, given the inverse relationship between prefrontal cortex activation and exercise-related affect (see e.g., Jones & Ekkekakis, 2019; Jones & Wheat, 2023). Collectively, the findings of this registered report offer strong support for the use of immersive technologies during bouts of repetitive, submaximal exercise as a means by which to enhance participants' psychological responses.

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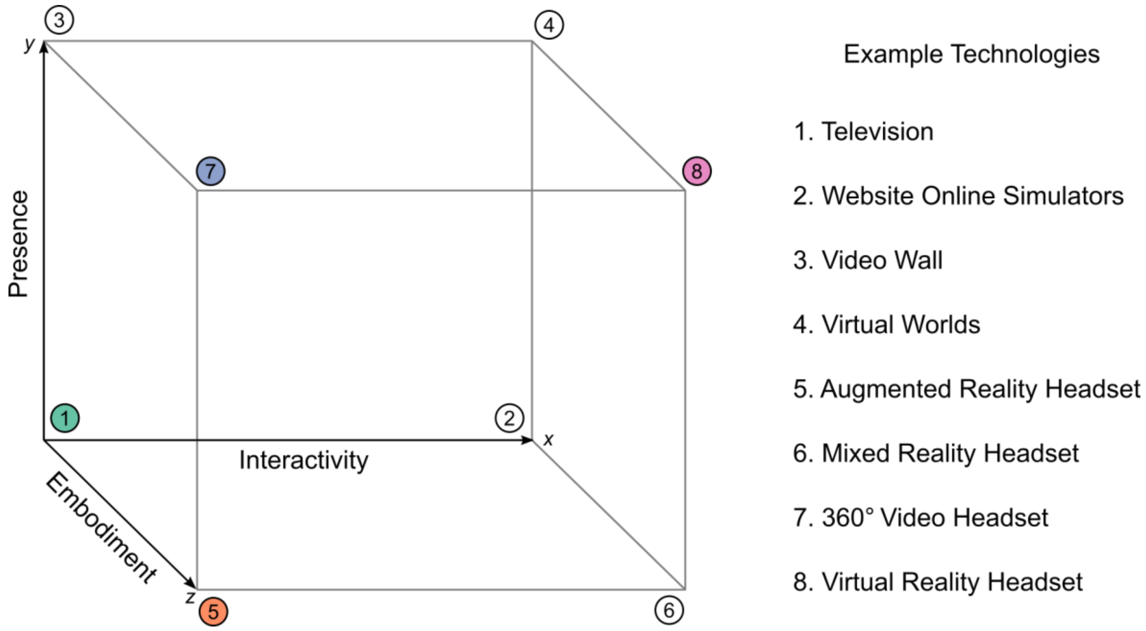
**Table 1**

*Inferential Statistics for All Dependent Variables*

| | *F* | *df* | *p* | $\eta_p^2$ |
|---|---|---|---|---|
| Affective Variables | | | | |
| Affective Valence – Baseline | | | | |
| Condition | 0.40 | 3, 69 | .751 | .02 |
| Affective Valence – Exercise | | | | |
| Condition × Timepoint | 1.96 | 9, 207 | .046 | .08 |
| Condition | 11.70 | 3, 69 | < .001 | .34 |
| Timepoint | 3.72 | 2, 37 | .043 | .14 |
| Affective Valence – Rebound | | | | |
| Condition × Timepoint | 3.62 | 3, 69 | .017 | .14 |
| Condition | 8.66 | 3, 69 | < .001 | .27 |
| Timepoint | 0.54 | 1, 23 | .470 | .02 |
| Perceptual Variables | | | | |
| Perceived Exertion | | | | |
| Condition × Timepoint | 0.74 | 5, 108 | .588 | .03 |
| Condition | 0.18 | 3, 69 | .908 | .01 |
| Timepoint | 37.03 | 2, 38 | < .001 | .62 |
| State Attention | | | | |
| Condition × Timepoint | 2.15 | 5, 109 | .069 | .09 |
| Condition | 9.29 | 2, 46 | < .001 | .29 |
| Timepoint | 7.63 | 2, 35 | .004 | .25 |
| Exercise Enjoyment | | | | |
| Condition | 25.57 | 3, 69 | < .001 | .53 |
| Remembered Pleasure | | | | |
| Condition | 18.38 | 3, 69 | < .001 | .44 |
| Forecasted Pleasure | | | | |
| Condition | 19.98 | 3, 69 | < .001 | .47 |
| Presence | | | | |
| Condition | 72.01 | 3, 69 | < .001 | .76 |

**Figure 1**

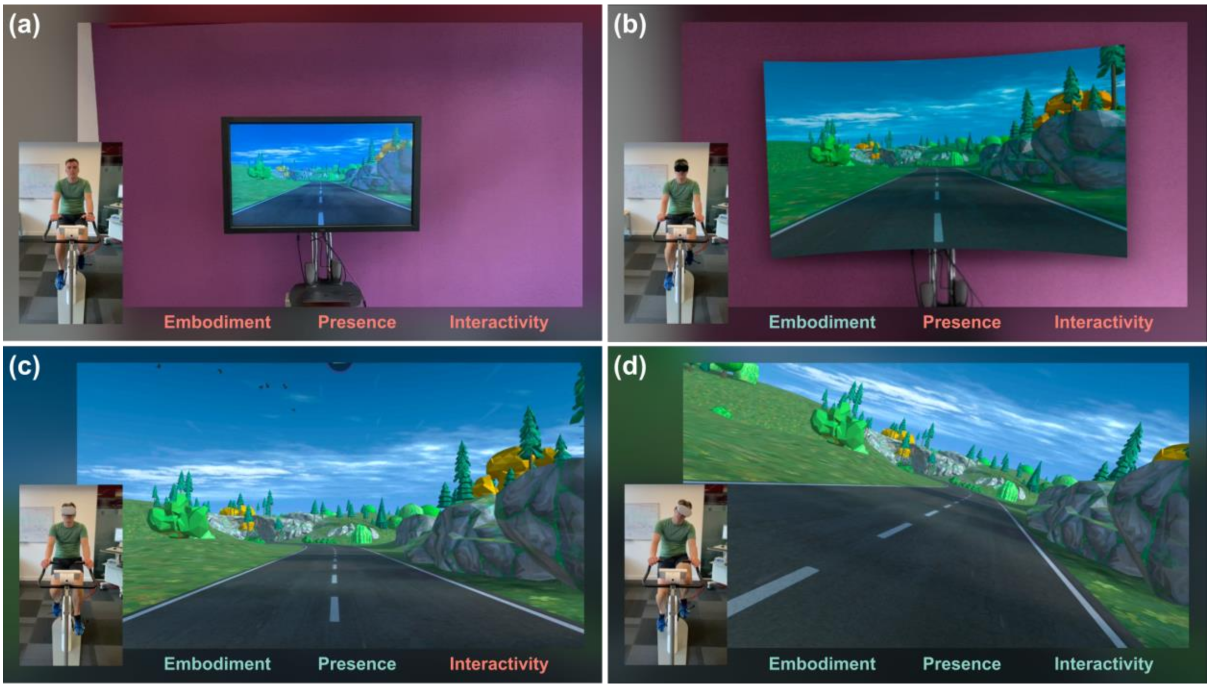
*The Embodiment–Presence–Interactivity (EPI) Cube*




*Note.* The EPI Cube depicts a range of technologies according to three dimensions: Embodiment (*z*-axis), Presence (*y*-axis) and Interactivity (*x*-axis). Coloured circles represent the technologies chosen for the present investigation. This enabled the construction of three repeated planned contrasts: Embodiment (Vertex 1 [low] vs. Vertex 5 [high]), Presence (Vertex 5 [low] vs. Vertex 7 [high]) and Interactivity (Vertex 7 [low] vs. Vertex 8 [high]). Adapted from Flavián et al. (2019).

**Figure 2**

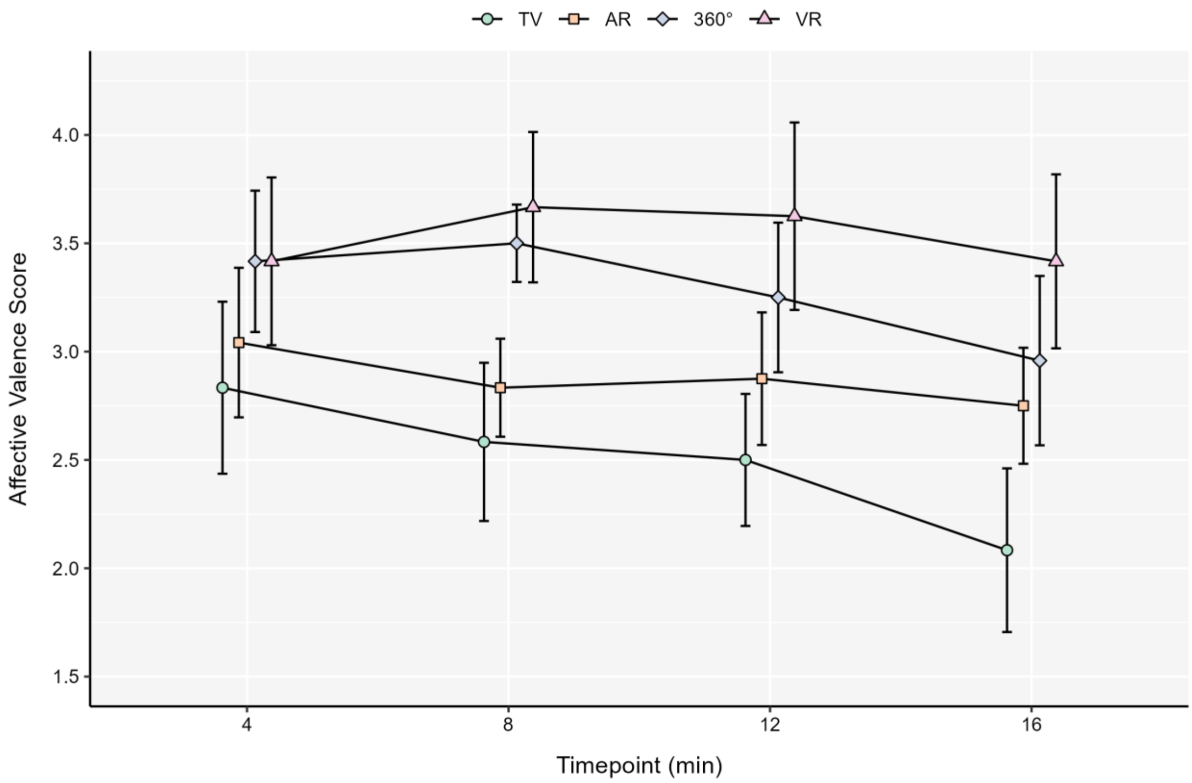
*Visual Stimuli Used in Experimental Trials*




*Note*. In experimental trials, participants exercised at ventilatory threshold under conditions that entailed use of television (a), augmented reality (b), 360° video (c), and virtual reality (d). See Supplementary Material 3 for additional information pertaining to the affordances of each technology.

**Figure 3**

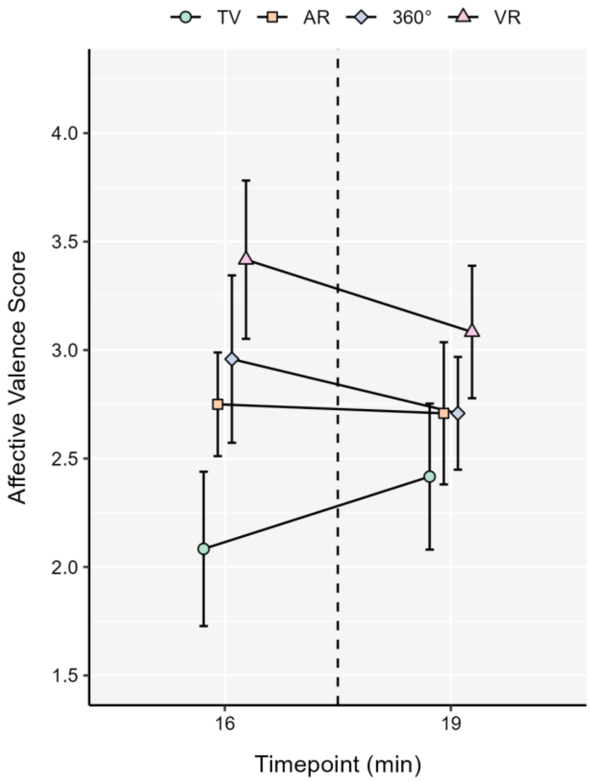
*Feeling Scale Responses Across Conditions*




*Note.* Error bars denote 95% CIs. Data points are dodged on the *x*-axis to prevent over-plotting. TV = television, AR = augmented reality, 360° = 360° video, VR = virtual reality.

**Figure 4**

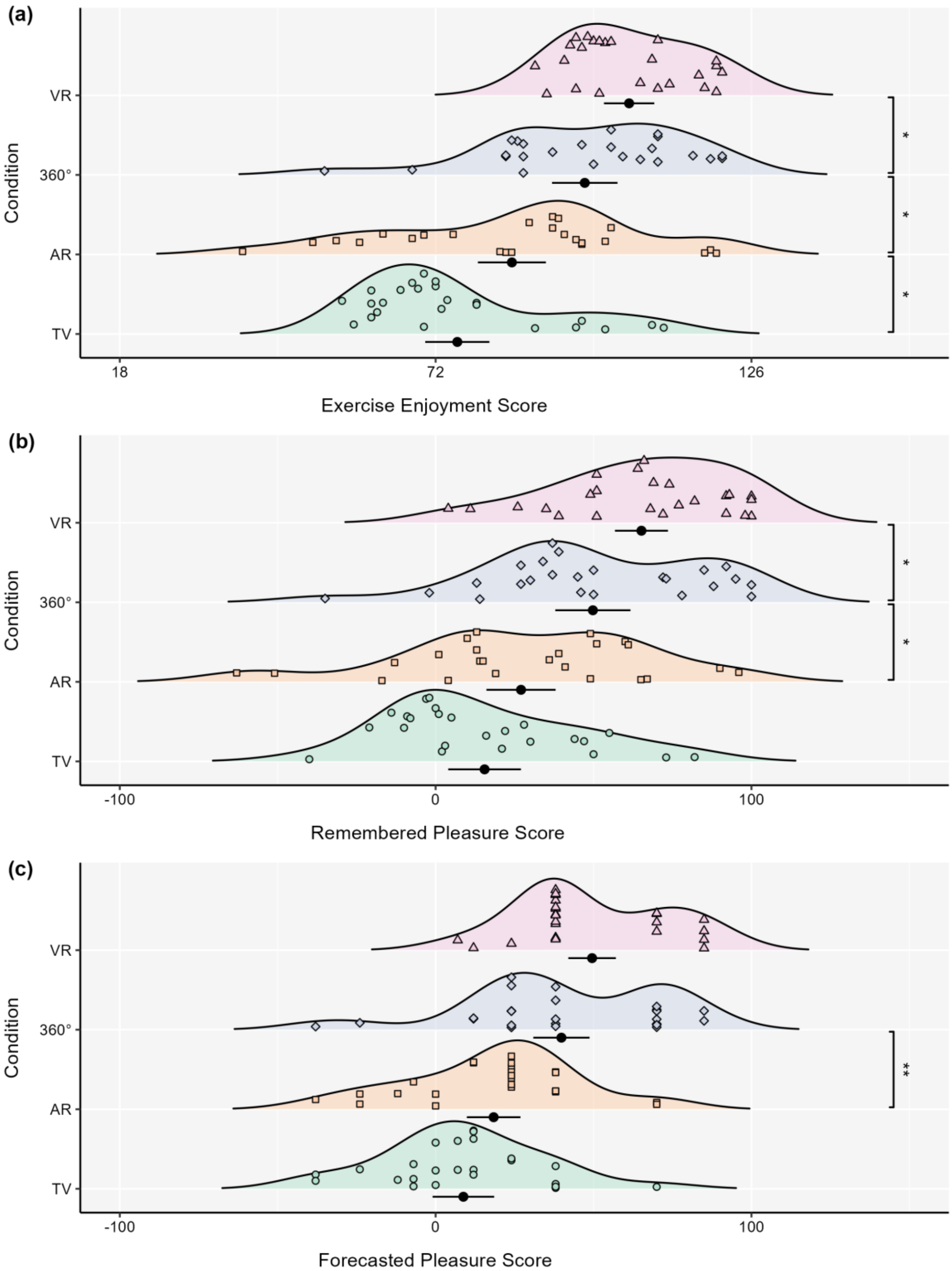
*Feeling Scale Responses Across Conditions*




*Note.* Error bars denote 95% CIs. Data points are dodged on the *x*-axis to prevent over-plotting. The dashed vertical line at 17.5 min represents the point at which the intensity of exercise decreased from ventilatory threshold to 20% below ventilatory threshold. TV = television, AR = augmented reality, 360° = 360° video, VR = virtual reality.

**Figure 5**

*Exercise Enjoyment (a), Remembered Pleasure (b) and Forecasted Pleasure (c) Responses Across Conditions*




*Note.* Each density plot is accompanied by the mean and 95% CI. TV = television, AR = augmented reality, 360° = 360° video, VR = virtual reality. * $p < .05$, ** $p < .01$.