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# *Ready Exerciser One*: Effects of music and virtual reality on cycle ergometer exercise

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**Objectives.** Physical inactivity remains a major global health concern, and researchers have been encouraged to explore the role of technology in the promotion of physical activity. Technologies that deliver audio-visual stimuli are frequently applied in the exercise domain. However, there is a paucity of research that examines the efficacy of modern virtual reality (VR) technology in this context. We investigated the effects of VR and music on affective, perceptual, enjoyment, and cardiac responses to aerobic-type exercise.

**Design.** A fully counterbalanced, within-subjects design was employed.

**Methods.** A convenience sample of recreationally active adult volunteers ($N$ = 24) completed a 12-min protocol during which they exercised under music, VR, VR-with-music, and control conditions.

**Results.** Analyses indicated a Condition × Time interaction for affective valence and perceived activation. Moreover, a main effect of condition emerged for state attention and perceived enjoyment. The VR and VR-with-music conditions elicited the most positive affective valence, highest levels of perceived activation, greatest number of dissociative thoughts, and most exercise enjoyment. Differences between these two conditions were negligible across the breadth of dependent variables.

**Conclusions.** The present findings illustrate the efficacy of modern VR technology in the exercise context, applied both with and without musical accompaniment. Additional research is required to assess the degree to which the findings are replicable among sedentary or ageing segments of the population. Given the emerging support pertaining to a positive relationship between affective responses and exercise adherence, VR technology should be considered as a means by which to promote an enjoyable exercise experience.



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## Statement of contribution

***What is already known on this subject?***

Physical inactivity remains a major global health concern (World Health Organization, 2018, *Eighth meeting of the European Union physical activity focal points network*). It has been suggested that a crucial factor that influences participation in health-related behaviours, such as physical activity, is an individual's affective response to the behaviour (Dunton et al., 2018, *Health Psychol.*, *37*, 915–923). Researchers have demonstrated that audio-visual stimuli administered via traditional displays (e.g., television screens, video projection) can positively influence exercise-related affect (Bigliassi, Greca, et al., 2019, *J. Sports Sci.*, *37*, 525–536; Jones et al., 2014, *J. Sport Exerc. Psychol.*, *36*, 528–541). However, there is a noticeable dearth of research that examines the effects of modern virtual reality (VR) technology on cycle ergometer exercise.

***What does this study add?***

- VR technology can render the exercise experience more pleasurable.
- VR might induce a higher perceptual load when compared to music, preventing interoceptive cues from entering focal awareness.
- Health psychologists are encouraged to explore the benefits of using modern VR to promote engagement in physical activity.

Given the numerous health benefits associated with physical activity, the World Health Organization (WHO) set a global target to reduce physical inactivity by 10% by 2025 (World Health Organization, 2018). Unfortunately, recent reports indicate that 'no country in the WHO European Region is on track to meet the [physical activity] target' (World Health Organization, 2018, p. 6). Accordingly, there is an urgent need to develop evidence-based interventions that seek to promote physical activity behaviours among the general population.

The lack of progress made towards increasing physical activity at the population-level has led researchers to question the efficacy of the 'rational education' approach, which has predicated public health campaigns for decades (Ekkekakis, Zenko, Ladwig, & Hartman, 2018). This approach assumes that individuals are rational and if provided with complete information pertaining to a behaviour, they are likely to change their behaviour in the desired manner (Ekkekakis, 2017). Nonetheless, it is quickly becoming evident that individuals often behave in ways that do not serve their self-interests (Ekkekakis & Zenko, 2016). It has been postulated that a crucial factor that influences participation in health-related behaviours such as physical activity is an individual's affective response to the behaviour (Dunton, Leventhal, Rothman, & Intille, 2018).

### *Affective responses to exercise*

We conceptualize affect as a dimensional domain comprised of affective valence and perceived activation. Predicated on psychological hedonism (Kahneman, 1999), the *affect heuristic* supports the notion that individuals are likely to engage in physical activity behaviours that result in pleasure and avoid those that result in displeasure (Williams, 2018). Thus, individuals who experience desirable affective states (i.e., high positive affect/low negative affect) during physical activity are more likely to adhere to an exercise programme (Dunton *et al.*, 2018).

The Dual-Mode Theory (DMT; Ekkekakis, 2003) explains how exercise intensity relates to the pleasure/displeasure individuals feel when engaged in exercise. A central tenet of DMT is that affective responses are determined by a combination of cognitive factors (e.g., physical self-efficacy) and interoceptive cues (e.g., elevated heart rate). Moreover, the theory defines exercise intensity with reference to metabolic indicators such as the ventilatory threshold (VT, the point at which breathing becomes laboured) and respiratory compensation point (RCP, which marks the onset of hyperventilation), both of which entail specific physiological changes (e.g., muscle acidosis; Ladwig, Hartman, & Ekkekakis, 2017).

The DMT posits that affective responses below VT are primarily influenced by cognitive factors and are pleasurable. Affective responses between the VT and the RCP are associated with the greatest inter-individual variability, wherein some exercisers experience pleasure and others displeasure. As the intensity of exercise exceeds the RCP, affective responses are primarily influenced by interoceptive cues and there is a near universal decline in pleasure, as the body enters a state of severe stress (Ladwig *et al.*, 2017).

### *Audio-visual stimuli within exercise contexts*

Technologies that deliver audio-visual stimuli are frequently used to enhance exercise-related affect. A vast corpus of research spanning the past two decades has demonstrated that listening to music can bolster affective responses to exercise across several modalities and intensities (Edworthy & Waring, 2006; Terry, Karageorghis, Curran, Martin, & Parsons-Smith, 2020). The term *attentional dissociation* is a frequently cited cognitive mechanism underlying such findings and refers to the way in which music has the capacity to guide attention outwardly (i.e., towards exteroceptive cues) and alleviate fatigue-related symptoms (Jones, Karageorghis, & Ekkekakis, 2014).

Researchers have also examined the effects of audio and visual stimuli in combination, including music-videos (Hutchinson, Karageorghis, & Black, 2017), television shows (Privitera, Antonelli, & Szal, 2014), and videos (Bigliassi, Greca, *et al.*, 2019). Moreover, scholars have administered visual stimuli that are congruent with the exercise protocols that they employ. For example, Jones *et al.* (2014) used rural parkland footage to accompany indoor cycle ergometry. They reported that music and music-video conditions elicited more positive exercise-related affect when compared to video and control conditions. Similarly, Barreto-Silva, Bigliassi, Chierotti, and Altimari (2018) administered pleasant, unpleasant, and neutral road-based footage while participants cycled at 5% above VT. The pleasant condition – depicting a cyclist on a descending course – facilitated a significantly lower rating of perceived exertion (RPE) when compared to the unpleasant condition.

Both teams of researchers predicated their audio-visual intervention on the concept of immersion as a means by which to encourage attentional dissociation. It was postulated that the greater the level of immersion, the greater the likelihood that participants would focus their attention outwardly (i.e., away from interoceptive cues). Moreover, that an immersive environment might up-/downregulate the effects of fatigue-related symptoms through cardiac responses such as heart rate variability (Barreto-Silva *et al.*, 2018). Immersive experiences were partially accomplished through use of video projection (Jones *et al.*, 2014) and a large television screen (Barreto-Silva *et al.*, 2018). Nonetheless, recent technological advances have afforded alternative modes of delivery that are capable of achieving far superior levels of immersion (Faric *et al.*, 2019).

### *Virtual reality headsets*

Virtual reality (VR) headsets are highly immersive because they replace real-sense perceptions with ones that are computer generated (Bailenson, 2018). This allows the user to perceive stimuli actively through natural sensorimotor contingencies (Slater, 2018). The close-to-life experience is achieved through a combination of wide-field-of-view vision, head tracking, low latency from head movements to display, high-resolution displays, and a capacity to accommodate a range of senses (Slater & Sanchez-Vives, 2016). Related to immersion, the term *presence* refers to the perceptual illusion of being inside the virtual environment despite the knowledge that one is not actually there (Slater, 2018). Hence, VR headsets are likely to induce greater perceptions of presence when compared to a range of traditional (e.g., television screens) and contemporaneous (e.g., augmented reality) displays.

Researchers have suggested that VR is efficacious in the treatment of post-traumatic stress disorder (PTSD; Maples-Keller, Yasinski, Manjin, & Rothbaum, 2017) and delivery of physical rehabilitation (Howard, 2017). Nonetheless, the application of modern VR headsets in an exercise context is surprisingly rare (Bird, Karageorghis, Baker, & Brookes, 2019; Matsangidou *et al.*, 2019). A notable exception concerns a pilot study by Zeng, Pope, and Gao (2017), who sought to compare the physiological and psychological effects of exercising on a VR-enabled cycle ergometer compared to a traditional ergometer. The findings from two 20-min bouts of exercise indicated that the VR condition elicited significantly lower RPE, which might be indicative of greater attentional dissociation. Moreover, the VR condition elicited higher scores for enjoyment and self-efficacy, both of which were measured upon completion of the exercise bout.

While the Zeng *et al.* (2017) study represents one of the first explorations into the effectiveness of commercially available VR-based exercise technology, a close examination of their methodology reveals several potential shortcomings. For example, Zeng *et al.* (2017) allowed participants to listen to music and watch videos during the traditional exercise condition, both of which can influence RPE and exercise-related affect (Bigliassi, Greca, *et al.*, 2019). They employed a fixed resistance during the VR-enabled condition but varied the resistance in the standard cycle ergometer condition. Further, the researchers used heart rate data to determine the resistance applied to the cycle ergometer, as opposed to defining the exercise intensity in accord with fixed metabolic indicators, such as VT (Ekkekakis, 2003). In sum, there is considerable scope to examine the psychological and psychophysiological effects of exercise with VR headsets while addressing the aforementioned limitations.

### *Aims and hypotheses*

The aim of the study was to investigate the effects of music, VR, and VR-with-music on the affective, perceptual, enjoyment, and cardiac responses to aerobic exercise. Five hypotheses were tested. Conditions containing VR would facilitate the most positive affective valence and highest perceived activation, followed by the music and control conditions, respectively ($H_1$). The control condition would elicit the steepest affective rebound (i.e., rise in affective valence on cessation of exercise), owing to participants' superior affective state during experimental conditions ($H_2$). Conditions containing VR would prompt: The most dissociative thoughts and lowest RPE ($H_3$); greatest perceived enjoyment ($H_4$); and least global activity of the autonomic nervous system (ANS) and the greatest parasympathetic activity ($H_5$), followed by music and control, respectively.

## Method

### *Participants*

A power analysis with power of .80, an alpha of .05 and $\eta_p^2$ of .33 in relation to the effects of auditory stimuli on affective valence during indoor cycle ergometry (Bigliassi, Karageorghis, Wright, Orgs, & Nowicky, 2017) was conducted using G*Power 3 (Faul, Erdfelder, Buchner, & Lang, 2009). The analysis indicated that 16 participants would be required and eight additional participants were recruited to facilitate a fully counterbalanced design. Ethical approval was granted by the College of Health and Life Sciences Ethics Committee at Brunel University London, UK. Following written informed consent, a convenience sample of 24 adult volunteers was recruited (10 women and 14 men; ethnicity = White British; $M_{\text{age}}$ = 26.7, $SD$ = 4.1 years; $M_{\text{BMI}}$ = 23.7, $SD$ = 5.2 kg/m$^2$). Recruitment was conducted through word-of-mouth and facilitated by means of promotional posters at the University of Gloucestershire, UK. Participants met three inclusion criteria: (1) recreationally active (according to the Physical Activity Readiness Questionnaire [PAR-Q]), (2) no hearing deficiency and/or visual impairment, and (3) familiar with cycle ergometry.

### *Experimental procedures*

Participants visited the laboratory on two occasions (i.e., one habituation/incremental exercise test and one experimental session) and were administered moderate-intensity bouts of exercise performed on a VR-enabled cycle ergometer (VirZOOM Bike Controller; Cambridge, MA, USA). Researchers have recently encouraged investigations of VR-enabled rhythmic-type exercise modalities, such as cycle ergometry (Perrin *et al*., 2019). Moreover, participants can engage in this exercise modality both with and without the use of a VR headset, thereby enabling the research team to elucidate the effects of VR on the exercise experience.

During habituation, each participant completed the PAR-Q and a demographic questionnaire. The participant's height, weight, and resting heart rate were then measured. Moreover, the psychological scales were presented to enable familiarization and minimize interpretation-related errors during the subsequent experimental phase. The participant was habituated to the VR headset (Samsung S8 and Samsung Gear VR; Suwon, Republic of Korea) and VR-enabled cycle ergometer. Thereafter, the participant removed the VR headset and completed an incremental exercise test on the VR-enabled cycle ergometer while wearing a heart rate monitor (Polar H7; Kempele, Finland) to ascertain VT. This physiological index was used to determine the relative exercise intensity for each participant during the experimental trials. Full details of the incremental cycle ergometer test can be found online (see Appendix S1).

A within-subjects design was adopted. Experimental testing took place at least 48 hr after the habituation session and at the same time of day. Participants were instructed to have adequate sleep the night before testing, avoid alcohol consumption, and refrain from ingesting caffeine on the day of the visit. Three experimental conditions (music, VR, and VR-with-music) and one control condition (no music and/or VR) were administered to identify the effects of audio-visual stimuli on affective, perceptual, enjoyment, and cardiac responses to cycle ergometry. In the music condition, participants were exposed to music while in a visually sterile environment. In the VR condition, participants were exposed to a VR experience by viewing it on a smartphone-powered VR headset. The VR-with-music condition entailed participating in the same VR experience while being exposed to music.

In the control condition, the participant was not exposed to music or VR. Furthermore, the participant's eyes and ears were not occluded in order to maintain ecological validity (Jones *et al*., 2014).

Conditions were counterbalanced and randomized with each experimental trial lasting a total of 12 min (warm-up [3 min], exercise [6 min], and warm-down [3 min]). It was anticipated that the inclusion of warm-up and warm-down periods would allow the research team to capture the dynamic nature of exercise-related affect and minimize the likelihood of injury to participants (Ekkekakis *et al*., 2018; Morales-Artacho, Lacourpaille, & Guilhem, 2017). Experimental manipulations coincided with the 6-min exercise phase. Work intensity increased from the warm-up (0–3 min: 20% below VT), to the exercise bout (3–9 min: 10% below VT), and decreased during the warm-down (9–12 min: 20 % below VT). All conditions were administered using the same cycle ergometer. A cycling computer and cadence sensor (Garmin Edge 1000; Olathe, KS, USA) were attached to the ergometer to ensure that cadence remained at $75 \pm 3$ rpm. Moreover, the first author monitored the participant's cadence in the VR and VR-with-music conditions and provided verbal feedback when necessary.

Recovery periods lasting 10 min were allocated in between trials, so that the participant's heart rate could descend to within 10% of their resting value. Word searches were administered during recovery periods to negate any potential carryover effects of previous conditions. The research team selected *There's Nothing Holdin' Me Back* (122 bpm) by Shawn Mendes and the VR experience *Cycle: Le Tour* (VirZOOM; Cambridge, MA, USA) for the experimental manipulation. Full details of the music and VR selection procedure can be found online (see Appendix S2).

### *Psychological measures*

Psychological measures were taken throughout the trials after 0.5, 2.5, 5.5, 8.5, and 11.5 min. Affective valence was assessed using the Feeling Scale (FS; Hardy & Rejeski, 1989) and perceived activation 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*). RPE was assessed using the Borg CR10 Scale (Borg, 1998), which is anchored by 0 (*nothing at all*) and 10 (*extremely strong*). Attentional focus was measured using Tammen's (1996) Attentional Scale (AS), which is anchored by 0 (*Internal focus* [*bodily sensations, heart rate, breathing etc*.]) and 100 (*External focus* [*daydreaming, external environment, etc*.]). Participants indicated their focus verbally during the exercise bout, with scores $> 50$ representing an external focus. The psychological measures were administered in the same order for each experimental trial (i.e., FS, FAS, RPE, AS). After the participant completed each trial, perceived enjoyment was assessed using the Physical Activity Enjoyment Scale (PACES; Kendzierski & DeCarlo, 1991). This scale includes 18 items attached to 7-point bipolar scales (e.g., 1 = *I enjoy it,* 7 = *I hate it* [item 1]).

### *Heart rate variability*

Heart rate variability data were recorded throughout each trial. Data were imported into Kubios software (Kubios HRV; Kuopio, Finland) and the signal broken down into four samples each lasting 3 min (Bigliassi *et al*., 2017). Two time-domain indices were extracted from the cardiac electrical signal. Standard deviation of normal-to-normal RR intervals (SDNN) was used as an index of global activity of the sympathetic–

parasympathetic system, and root mean square of successive RR interval differences (RMSSD) was used as an index of parasympathetic activity (Acharya, Joseph, Kannathal, Lim, & Suri, 2006).

### *Data analysis*

Data were screened for univariate outliers using standardized *z*-scores ($z > \pm 3.29$) and multivariate outliers using the Mahalanobis distance test ($p < .001$; Tabachnick & Fidell, 2018). Data were examined for the parametric assumptions that underlie (M)ANOVA (Tabachnick & Fidell, 2018). Affective variables (affective valence and perceived activation) were analysed using a 4 (Condition) × 5 (Time) MANOVA. Perceptual variables (RPE and attentional focus) were analysed using a 4 (Condition) × 2 (Time) MANOVA. Perceived enjoyment was assessed using repeated-measures (RM) ANOVA. Cardiac variables (SDNN and RMSSD) were analysed using a 4 (Condition) × 4 (Time) MANOVA. Greenhouse–Geisser adjustments were made to *F* tests in which the sphericity assumption was violated. Where the *F* ratio was significant, Bonferroni-adjusted pairwise comparisons or checks of standard errors were employed to identify differences.

## Results

Data screening revealed seven univariate outliers ($z > \pm 3.29$) pertaining to cardiac values and, in all instances, the score was adjusted by assigning the outlying cases a raw score that was one unit larger (or smaller) than the next most extreme score in the distribution until $z < \pm 3.29$ (Tabachnick & Fidell, 2018). Tests of the distributional properties of the data in each cell of the analysis revealed violations of normality in 26 of the 92 cells. Seventeen of the violations were associated with the cardiac variables, which displayed positive skewness coupled with leptokurtosis. Accordingly, square root transformations were applied to normalize these data. Follow-up tests revealed violations of normality in nine of the 92 cells (seven at $p < .05$ and two at $p < .001$), associated with the affective and perceptual variables. We did not transform these data owing to concerns regarding transformation of subjective data derived from Likert scales (Nevill & Lane, 2007). No multivariate outliers were identified.

### *Affective variables*

The omnibus analysis revealed a significant Condition × Time interaction for affective valence ($p = .001$, $\eta_p^2 = .14$; see Table 1). VR elicited significantly higher affective valence during the exercise bout (i.e., after 5.5 and 8.5 min) when compared to control and music conditions (see Figure 1a). There was a significant Condition × Time interaction for perceived activation ($p < .001$, $\eta_p^2 = .24$; see Table 1). VR and VR-with-music conditions elicited significantly higher perceived activation ratings during the exercise bout compared to music and control conditions (see Figure 1b).

There was a main effect of condition for affective valence ($p = .029$, $\eta_p^2 = .12$) and perceived activation ($p < .001$, $\eta_p^2 = .35$). Pairwise comparisons indicated that affective valence was significantly higher for VR compared to control ($p = .017$, 95% CI [0.06, 0.78]). Furthermore, the VR and VR-with-music conditions elicited significantly higher perceived activation compared to control ($p = .002$, 95% CI [0.16, 0.86] and $p = .007$, 95% CI [0.10, 0.82], respectively) and music conditions ($p = .003$, 95% CI [0.11, 0.61] and $p = .016$, 95% CI [0.04, 0.57], respectively).

**Table 1.** Inferential statistics for all dependent variables

| | Pillai's trace | $F$ | $df$ | $p$ | $\eta_p^2$ |
|---|---|---|---|---|---|
| Affective variables | | | | | |
| Condition × Time | .322 | 4.42 | 24, 552 | < .001 | .16 |
| Affective valence | – | 3.78 | 6, 146 | .001 | .14 |
| Perceived activation | – | 7.27 | 6, 134 | < .001 | .24 |
| Condition | .382 | 5.44 | 6, 138 | < .001 | .19 |
| Affective valence | – | 3.19 | 3, 69 | .029 | .12 |
| Perceived activation | – | 12.16 | 2, 49 | < .001 | .35 |
| Time | .618 | 10.29 | 8, 184 | < .001 | .31 |
| Affective valence | – | 3.72 | 2, 51 | .027 | .14 |
| Perceived activation | – | 31.39 | 2, 50 | < .001 | .58 |
| Perceptual variables | | | | | |
| Condition × Time | .061 | 0.72 | 6, 138 | .636 | .03 |
| Perceived exertion | – | 0.70 | 3, 69 | .553 | .03 |
| State attention | – | 0.78 | 2, 53 | .482 | .03 |
| Condition | .272 | 3.63 | 6, 138 | .002 | .14 |
| Perceived exertion | – | 0.02 | 3, 69 | .997 | .00 |
| State attention | – | 7.90 | 2, 48 | .001 | .26 |
| Time | .366 | 6.35 | 2, 22 | .007 | .37 |
| Perceived exertion | – | 13.06 | 1, 23 | .001 | .36 |
| State attention | – | 1.13 | 1, 23 | .299 | .05 |
| Perceived enjoyment | | | | | |
| Condition | – | 22.09 | 2, 36 | < .001 | .49 |
| Cardiac variables | | | | | |
| Condition × Time | .109 | 1.33 | 18, 414 | .163 | .06 |
| SDNN | – | 2.55 | 9, 207 | .009 | .10 |
| RMSSD | – | 1.45 | 4, 81 | .231 | .06 |
| Condition | .050 | 0.60 | 6, 138 | .734 | .03 |
| SDNN | – | 0.69 | 3, 69 | .564 | .03 |
| RMSSD | – | 1.06 | 3, 69 | .370 | .04 |
| Time | .870 | 17.71 | 6, 138 | < .001 | .44 |
| SDNN | – | 109.48 | 2, 47 | < .001 | .83 |
| RMSSD | – | 64.73 | 2, 40 | < .001 | .74 |

*Note*. RMSSD = root mean square of successive RR interval differences; SDNN = standard deviation of normal-to-normal RR intervals.

### *Perceptual variables*

The omnibus analysis indicated that the Condition × Time interaction was non-significant ($p$ = .636, $\eta_p^2$ = .03; see Table 1). There was, however, a main effect of condition that applied to state attention ($p$ = .001, $\eta_p^2$ = .26). Pairwise comparisons showed that the VR and VR-with-music conditions prompted significantly greater external focus when compared to the control condition ($p$ = .036, 95% CI [0.76, 31.32] and $p$ = .004, 95% CI [4.69, 30.72], respectively; see Figure 2).

### *Perceived enjoyment*

RM ANOVA indicated a significant main effect of condition ($p$ < .001, $\eta_p^2$ = .49; see Table 1). Pairwise comparisons showed that the VR and VR-with-music conditions elicited significantly greater enjoyment when compared to control ($p$ < .001, 95% CI [8.94, 32.81]

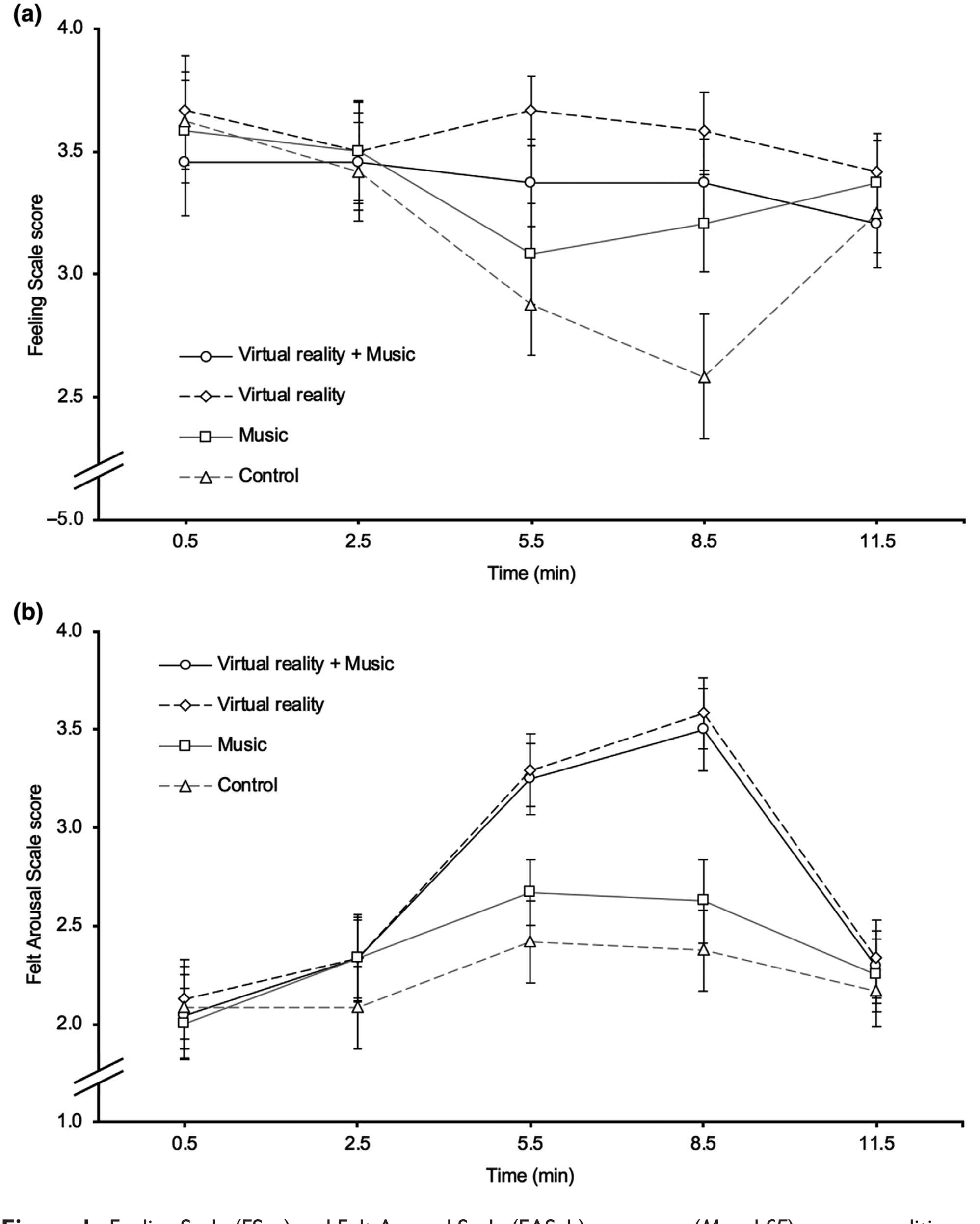


**Figure 1.** Feeling Scale (FS; a) and Felt Arousal Scale (FAS; b) responses (*M* and *SE*) across conditions.

and $p < .001$, 95% CI [9.81, 33.11], respectively) and music conditions ($p = .001$, 95% CI [4.93, 24.40] and $p < .001$, 95% CI [6.24, 24.26], respectively; see Figure 3).

### *Cardiac variables*

The omnibus analysis indicated that the Condition × Time interaction was non-significant ($p = .163$, $\eta^2_p = .06$; see Table 1). Nonetheless, there was a main effect of time for SDNN ($p < .001$, $\eta^2_p = .83$) and RMSSD ($p < .001$, $\eta^2_p = .74$). SDNN and RMSSD

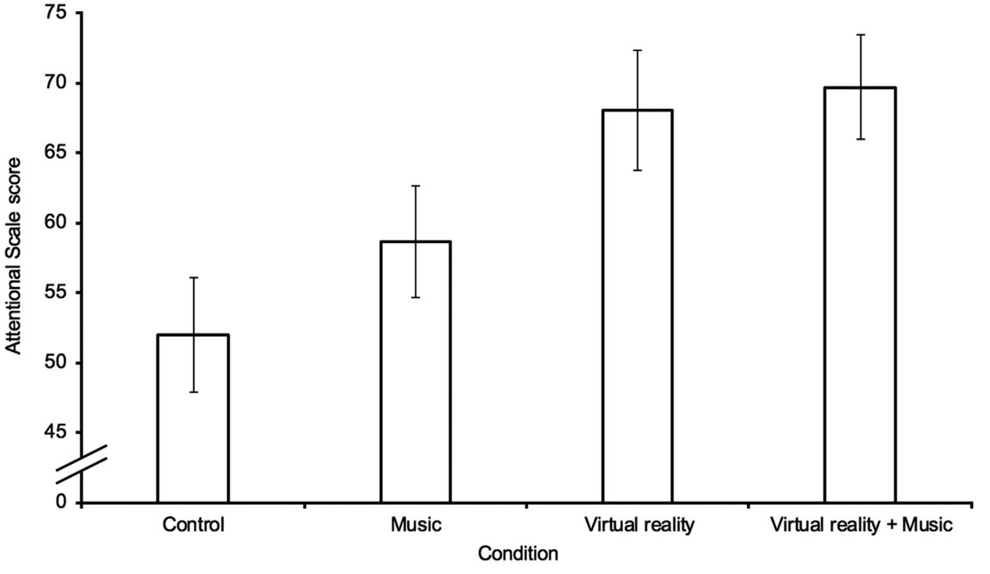


**Figure 2.** Attentional Scale responses (*M* and *SE*) across conditions.

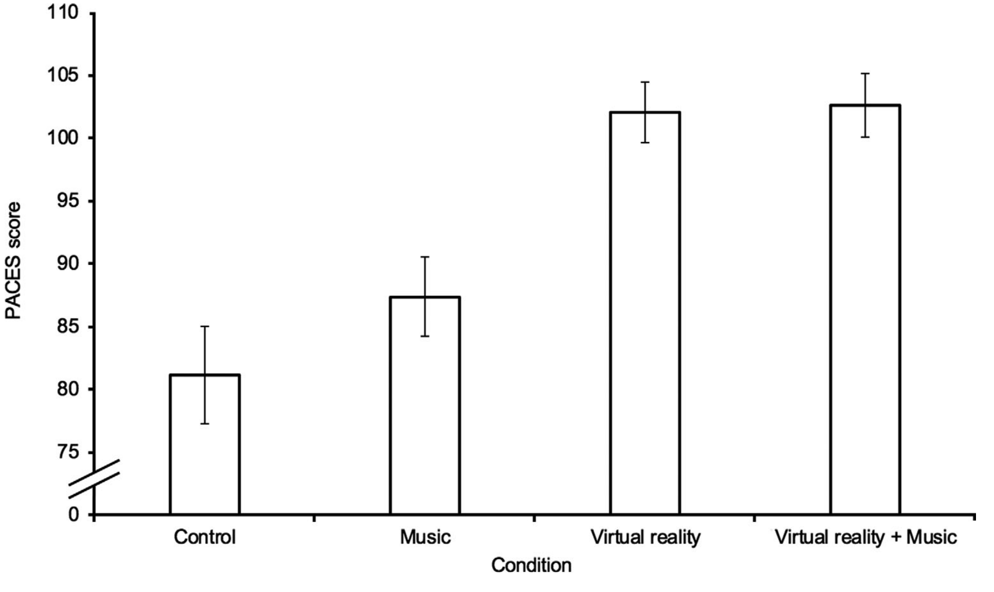


**Figure 3.** Physical Activity Enjoyment Scale responses (*M* and *SE*) across conditions.

values decreased incrementally throughout the exercise bout and subsequently increased during the warm-down phase.

## Discussion

The aim of this study was to explore responses to a range of audio-visual stimuli during aerobic cycle ergometry. The sample was comprised of relatively young, recreationally active adults; accordingly, the findings cannot be generalized to the entire UK population. The hypothesis that VR would facilitate the most positive affective valence and highest perceived activation, followed by the music and control conditions, respectively ($H_1$), was accepted. The finding that audio-visual stimuli can enhance affective valence during exercise when compared to control conditions aligns with previous findings (Hutchinson *et al.*, 2017; Jones *et al.*, 2014). However, this study is one of the first to demonstrate that a VR condition can render the exercise experience more pleasurable when compared to music and control conditions.

The most positive affective valence was reported in the VR and VR-with-music conditions during the exercise bout (i.e., after 5.5 and 8.5 min; see Figure 1a). Researchers have seldom employed a video-only condition when examining exercisers' affective responses to audio-visual stimuli. A notable exception concerns Jones *et al.* (2014), who reported significantly higher affective valence scores in a music and video condition when compared to video. It was, therefore, somewhat unexpected that the present participants reported greater pleasure when exercising with VR versus VR-with-music (i.e., $M$ = 3.63 vs. $M$ = 3.38). We made use of experimenter-selected rather than participant-selected music (Hutchinson *et al.*, 2018), and so it is possible that a lack of music familiarity bore influence on participants' affective valence scores during the exercise bout (Karageorghis, 2017). This is plausible given that users of VR exergames have cited music as a central component of their gaming experience (Faric *et al.*, 2019).

The Condition × Time interaction effect for perceived activation showed that participants derived greater stimulation from all experimental conditions when compared to control (see Figure 1b). These findings add weight to the notion that music can elevate perceived activation during exercise (Hutchinson & Karageorghis, 2013). However, it is noteworthy that the VR and VR-with-music conditions elicited significantly greater perceived activation when compared to the music condition. This finding does not concur with the comparable finding of Jones *et al.* (2014), who reported that music elicited greater perceived activation than video during cycle ergometry. These authors suggested that their video content lacked stimulative qualities, although the visual stimuli used in the present investigation were of a similar nature (i.e., depicting a first-person perspective rural scene). Accordingly, the presence afforded by the VR headset elevated participants' perceived activation during exercise (Diemer, Alpers, Peperkorn, Shiban, & Mühlberger, 2015). This is conceivable given that no differences across conditions were found during the warm-down (after 11.5 min), before which participants were required to remove the VR headset.

We hypothesized that the control condition would be associated with the steepest affective rebound, owing to participants' more positive affective state during experimental conditions ($H_2$). The greatest difference in affective valence scores from the final in-task measurement (i.e., after 8.5 min) to the final measurement taken during the warm-down was observed in the control condition ($M_{\text{diff}}$ = 0.67; see Figure 1a), and thus, $H_2$ was accepted. This finding supports the notion that a rapid increase in pleasure is expected immediately following cessation of exercise that is perceived as unpleasant (Ekkekakis, Parfitt, & Petruzzello, 2011).

The hypothesis that the VR and VR-with-music conditions would facilitate the most dissociative thoughts and lowest RPE, followed by the music and control conditions ($H_3$) was partially accepted. Specifically, this outcome was observed only in state attention. The finding that audio-visual stimuli can promote attentional dissociation is consistent with previous research (Bigliassi, Greca, *et al.*, 2019; Jones *et al.*, 2014). It has been suggested that plural stimuli provide a more potent form of distraction during exercise when compared to a singular stimulus (e.g., music or video; Hutchinson *et al.*, 2017). However, participants dissociated to a similar extent in the VR (*M* = 68.02) and the VR-with-music condition (*M* = 69.69). Accordingly, we encourage researchers to consider not only the content of audio-visual stimuli, but also the means by which audio-visual stimuli are delivered in an exercise context. One of the key features of VR headsets is the capacity to occlude the user from physical reality (Bailenson, 2018), making the experience more immersive than either video projection (Jones *et al.*, 2014) or television screens (Barreto-Silva *et al.*, 2018).

Despite capturing participants' attention, it appears that the experimental manipulation had no bearing on RPE. This was an unexpected finding that precluded full acceptance of $H_3$. Moreover, the finding is inconsistent with previous research that has found VR to be effective in reducing RPE scores during exercise when compared to non-VR control conditions (Matsangidou *et al.*, 2019; Zeng *et al.*, 2017). Nonetheless, it is noteworthy that participants' RPE scores were relatively low across all conditions ($M = 2.87 \pm 0.02$). The present participants were healthy individuals who regularly engaged in exercise, which might account for this. They are likely to have developed a high tolerance for exercising at intensities proximal to the VT and this explanation is even more plausible when the RPE scores are considered in tandem with elevated affective valence scores (see Figure 1a). Alternatively, it is possible that the employed exercise duration was not of sufficient length to elicit differences in RPE across conditions.

The hypothesis that conditions involving VR would facilitate the greatest perceived enjoyment, followed by music and control ($H_4$) was accepted. Several researchers have demonstrated that music can engender greater exercise-related enjoyment (Jones *et al.*, 2014; Stork, Kwan, Gibala, & Martin Ginis, 2015). Moreover, the present findings add weight to the notion that exercise-related enjoyment can be bolstered by virtual environments (Farrow, Lutteroth, Rouse, & Bilzon, 2019; Zeng *et al.*, 2017). These findings are encouraging given the burgeoning corpus of research that has emphasized a positive relationship between affective responses and adherence to exercise (Williams, 2018).

The hypothesis that conditions containing VR would elicit the least global activity of the ANS and the greatest parasympathetic activity, followed by music, and control ($H_5$) was not supported. Ostensibly, the selected exercise intensity (10% below VT) had a greater influence on cardiac stress than the audio-visual stimuli administered during experimental conditions, which is consistent with previous findings (Bigliassi *et al.*, 2017). Close examination of the results provides support for an exercise intensity dose-response, wherein participants' SDNN and RMSSD values decreased throughout the exercise bout and rebounded during warm-down (Michael, Graham, & Davis, 2017).

### *Theoretical and practical implications*

The present results are novel in demonstrating that modern VR technology can enhance affective states when young, healthy participants exercise at an intensity proximal to VT; this might hold value in the promotion of exercise adherence. One of the salient mechanisms underlying the effects of audio-visual stimuli in the context of exercise concerns attentional processing (Bird *et al.*, 2019). Perceptual load theory supports the notion that perception has a limited capacity that proceeds until it is filled (Murphy, Groeger, & Greene, 2016). When an individual is engaged with a task that imposes high perceptual load, distractors cannot be processed. Alternatively, when an individual is engaged with a low perceptual load task, all available stimuli are processed.

We hypothesize that VR technology induces a higher perceptual load when compared to music and control conditions, which prevent exercise-related interoceptive cues from entering focal awareness. It is plausible that such effects can be attributed to the high degree of presence afforded by modern VR headsets (Faric *et al.*, 2019; Slater & Sanchez-Vives, 2016). Indeed, the perceptual illusion of presence has been postulated to activate several areas of the brain, including the dorsal and ventral visual stream, the parietal cortex, the premotor cortex, mesial temporal area, the brainstem, and the thalamus (Jäncke, Cheetham, & Baumgartner, 2009).

In addition to the concept of presence, we hypothesize that a VR headset provides stimuli with which participants became unconsciously entwined. It has been postulated that mirror neurons in the premotor and parietal cortex discharge when an individual performs an action and when they observe another performing the same action (Kim, 2013). Moreover, there is evidence that the bodily states of observed others can stimulate similar bodily states in the self (cf., *bodily resonance;* Maister, Slater, Sanchez-Vives, & Tsakiris, 2015). Hence, it is plausible that participants mirrored the behaviours and affective states of the non-player characters depicted in the VR experience.

From a practical perspective, the present results provide evidence that modern VR headsets are effective in rendering the exercise experience more pleasant. This is noteworthy given the burgeoning body of work that has emphasized a positive relationship between affective responses and adherence to exercise (Ekkekakis *et al.*, 2018; Williams *et al.*, 2016). Understanding how technology can be harnessed to promote physical activity has been highlighted as an important direction for future research (Lewis, Napolitano, Buman, Williams, & Nigg, 2017). Accordingly, the present findings are timely and address the lack of practical information that pertains to enhancement of exercise-related affect (Zenko, Ekkekakis, & Ariely, 2016). Researchers and health professionals are encouraged to explore the potential benefits of employing VR headsets in the exercise context as a means by which to reduce the disconcerting number of people in the developed world who refrain from engagement in regular physical activity (World Health Organization, 2018). The ever-increasing rate at which VR is becoming accessible means that virtual experiences will be readily available to a large consumer base in the near future.

### Strengths and limitations

The present investigation represents one of the first attempts to examine commercially available audio-visual stimuli administered via a VR headset during exercise. The findings extend and add weight to a recent pilot study (Zeng *et al.*, 2017), while addressing a number of methodological shortcomings evident in that study. Foremost among these were greater control over the audio-visual stimuli employed during each condition and the full counterbalancing of conditions to reduce the influence of order effects. In addition, we assessed each participant's VT prior to conducting the experimental trials, which enabled us to standardize exercise intensity as well as reduce inter-individual variability in metabolic state; a vital consideration when responding to affect-related measures (Ekkekakis, 2003).

In terms of possible limitations, it is possible that the duration and repetitiveness associated with an extended piece of music was unfamiliar to participants. We selected the music for its motivational qualities and with a view to eliminating the possibility of auditory-motor synchronization (Karageorghis, 2017). However, it is acknowledged that exercisers rarely listen to one piece of music for an entire exercise bout. An alternative approach would have entailed segueing multiple selections into a playlist (e.g., Jones *et al.*, 2014), which would have enhanced the ecological validity associated with the experimental manipulation.

Another possible limitation pertains to responding to psychological scales while wearing a VR headset. We endeavoured to reduce the impact of this by familiarizing participants to the scales upon their entry to the laboratory. Moreover, the scales were administered verbally in conditions that contained the use of VR. Finally, we employed a homogenous sample that consisted largely of young, healthy individuals who regularly engage in exercise. Accordingly, the present findings should be interpreted with due caution and not generalized without replication using samples that are more representative of the wider UK population.

### *Future directions*

Future work might entail longer exercise protocols than the one employed herein. Nonetheless, it is important to note that a possible side effect of using VR headsets in an exercise context is simulation sickness (Faric *et al.*, 2019; Slater & Sanchez-Vives, 2016). Researchers are therefore encouraged to employ VR-enabled exercise protocols that span relatively short durations (e.g., up to 20 min) and to schedule regular breaks in order to reduce the likelihood of sickness (Bailenson, 2018). A further avenue for future research entails the use of alternative exercise intensities, such as those predicated on self-paced exercise (Hutchinson *et al.*, 2018).

Another line might entail employing intensities that are proximal to VT. However, it is likely that exercising at such an intensity would cause a VR headset to steam up if used over a prolonged period. It is currently unknown whether the use of VR exergames declines over time, as users become overly familiar with game design (Faric *et al.*, 2019; Jones & Ekkekakis, 2019). Hence, there is a need for researchers to examine the influence of VR-mediated exercise on long-term health outcomes. Scholars might focus their attention on more heterogeneous samples than the one recruited for the present study, with the inclusion of sedentary individuals or older adults (Matsangidou *et al.*, 2019). In addition, future work should seek to further understanding of the psychophysiological mechanisms that underlie the effects of audio-visual stimuli in an exercise context. Work of this nature might incorporate techniques such as electroencephalography and/or functional near-infrared spectroscopy (Bigliassi, Karageorghis, Hoy, & Layne, 2019).

### *Conclusions*

The current findings provide evidence that audio-visual stimuli administered via modern VR headsets can assist in the promotion of a pleasurable exercise experience. This is predicated on the findings from several dependent variables given that the technology-mediated exercise was associated with more positive affective valence, greater perceived activation, more dissociative thoughts, and higher ratings of post-exercise enjoyment. It is noteworthy that the aforementioned effects were observed not only when compared to the control condition, but also when compared to the music condition. There is evidence amassing that points to a link between exercise-related affect and adherence (Ekkekakis *et al.*, 2018; Williams *et al.*, 2016). In addition, researchers have been encouraged to consider how technology can provide the keystone for interventions that seek to promote regular engagement in physical activity (Lewis *et al.*, 2017). Accordingly, modern VR technology should be considered by health psychologists and exercise practitioners as a useful tool through which to facilitate a pleasurable exercise experience.

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## Conflicts of interest

The authors declare no conflicts of interest.

## Author contributions

Jonathan M. Bird (Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Visualization; Writing – original draft; Writing – review and editing); Costas I. Karageorghis, PhD (Conceptualization; Formal analysis; Investigation; Methodology; Project administration; Supervision; Validation; Writing – original draft; Writing – review and editing); Steven J. Baker (Conceptualization; Formal analysis; Writing – review and editing); David A. Brookes (Conceptualization; Formal analysis; Writing – review and editing); Alexander V. Nowicky (Conceptualization; Formal analysis; Writing – review and editing).

## Data availability statement

The data associated with this study are available from the corresponding author upon request.

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## Supporting Information

The following supporting information may be found in the online edition of the article:

**Appendix S1.** Incremental cycle ergometer test procedure.

**Appendix S2.** Music and virtual reality selection procedure.