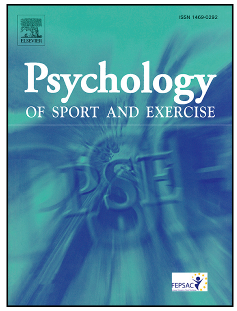
Journal Pre-proof



One-HIIT Wonder: Can Music Make High-Intensity Interval Training More Pleasant?

Costas I. Karageorghis, Ségolène M.R. Guérin, Layan Fessler, Luke W. Howard, Calum Pinto, Oluwatobiloba Ojuri, Joy Kuan, Kristian G. Samwell-Nash

PII: S1469-0292(24)00128-6

DOI: https://doi.org/10.1016/j.psychsport.2024.102717

Reference: PSYSPO 102717

To appear in: *Psychology of Sport & Exercise*

Received Date: 7 March 2024

Revised Date: 5 July 2024

Accepted Date: 3 August 2024

Please cite this article as: Karageorghis, C.I., Guérin, S.M.R., Fessler, L., Howard, L.W., Pinto, C., Ojuri, O., Kuan, J., Samwell-Nash, K.G., One-HIIT Wonder: Can Music Make High-Intensity Interval Training More Pleasant?, *Psychology of Sport & Exercise*, https://doi.org/10.1016/j.psychsport.2024.102717.

One-HIIT Wonder: Can Music Make High-Intensity Interval Training More Pleasant?

Costas I. Karageorghis[1], Ségolène M. R. Guérin[2], Layan Fessler[3], Luke W. Howard[1], Calum Pinto[1], Oluwatobiloba Ojuri[1], Joy Kuan[1] and Kristian G. Samwell-Nash[1]

[1]Department of Life Sciences, Brunel University London, Middlesex, United Kingdom

[2]Institute of Neuroscience, Université Catholique de Louvain, Brussels, Belgium

[3] Univ. Grenoble-Alpes, SENS, F-38000 Grenoble, France

Resubmitted: 5 July 2024

Author Note

Costas I. Karageorghis https://orcid.org/0000-0002-9368-0759

Ségolène M. R. Guérin https://orcid.org/0000-0003-0990-9408

Layan Fessler https://orcid.org/0000-0002-8435-5110

Luke W. Howard https://orcid.org/0000-0002-4613-0404

Calum Pinto https://orcid.org/0009-0006-5207-2737

Oluwatobiloba Ojuri https://orcid.org/0009-0003-6576-7755

Joy Kuan https://orcid.org/0009-0003-7016-8159

Kristian G. Samwell-Nash https://orcid.org/0009-0002-9632-9646

The study data are shared openly as part of the publication of the article (https://doi.org/10.5281/zenodo.10000570). Correspondence concerning this article should be addressed to Costas I. Karageorghis, Department of Life Sciences, Brunel University London, UB8 3PH, United Kingdom (costas.karageorghis@brunel.ac.uk).

Running Head: RESPITE–ACTIVE MUSIC IN HIIT

One-HIIT Wonder: Can Music Make High-Intensity Interval Training More Pleasant?

Submitted: 5 July 2024

Abstract

The use of music as an aid to recovery during and after exercise is an area of growing scientific interest. We investigated the effects of in-task, asynchronous music and respite–active music (i.e., music used for active recovery in between high-intensity exercise bouts) on a range of psychological, psychophysical and psychophysiological outcomes. Participants (*N* = 28; 14 females) made five laboratory visits for: (a) pre-test/familiarisation; (b) fast-tempo music during supramaximal exercise bouts and medium-tempo during active-recovery periods; (c) fast-tempo during exercise and no music during recovery; (d) no music during exercise and medium-tempo during recovery; and (e) a no-music (throughout) control. A cycle ergometer-based HIIT protocol comprising 6 × 60-s bouts at 100% Wmax with 75-s active recovery was administered. Measures were taken at the end of supramaximal bouts and active recovery periods (RPE, state attention, core affect, state motivation), then upon cessation of the protocol (remembered pleasure and exercise enjoyment). Heart rate and heart rate variability (HRV) measures were taken throughout. The music manipulations only had an effect on state motivation, which was higher (p = .036) in the fast tempo–medium tempo condition compared to no-music control (Cohen's d = 0.49), and the SDNN component of HRV, which was lower (p = .007) in the fast tempo–no music condition compared to control (Cohen's d = 0.32). Collectively, the present findings do not support any of the study hypotheses regarding the music-related manipulations, and do not concur with the findings of related studies (e.g., Karageorghis et al., 2021). The unexpected results are discussed with reference to extant theory, and recommendations are offered in regard to music-related applications.

Keywords: affective arousal, affective valence, dissociation, Dual-Mode Theory, entrainment, exercise hedonics

One-HIIT Wonder: Can Music Make High-Intensity Interval Training More Pleasant?

Recovery in the exercise domain is an important facet of performance and germane to the achievement of incremental fitness gains. It is, however, often not given due consideration by exercisers or exercise scientists (Kellman & Beckmann, 2024; Peake, 2019). Recovery can be defined as the organism's return to baseline or resting state, and its optimisation has implications for the degree to which recreationally active individuals both enjoy and adhere to exercise (Kassavou et al., 2014). Most of the studies that have examined the psychological, psychophysical and psychophysiological effects of music in the realm of exercise have focused on pre-task and in-task applications (see Karageorghis, 2020 for a review and Terry et al., 2020 for a meta-analysis). To date, little attention has been given to the use of music as an aid to recovery in between bouts of high-intensity exercise.

An important distinction in the music–exercise-recovery literature, not always made explicit by researchers (e.g., Jia et al., 2016), has entailed the use of music for movement-based recovery, known as *active recovery*, and static recovery, known as *passive recovery* (Karageorghis, 2017). Another important distinction is that between *respite music* – used to interleave high-intensity exercise bouts – and *recuperative music*, which entails use of slow/sedative music at the very end of an exercise session (Jones et al., 2017; Karageorghis, 2020) to expedite the organism's return to physiological homeostasis. Most recovery-oriented studies in this subset of the exercise psychology literature have examined the application of recuperative music (e.g., Jing & Xudong, 2008; Karageorghis et al., 2018), while only a handful have focused on respite music (e.g., Hutchinson et al., 2020, Jones et al., 2020). All such studies seek to exploit the biomusicological principle of *entrainment*, which concerns bodily pulses such as heart rate (HR), respiration rate and brainwaves being drawn into a common oscillation with musical tempo (Terry et al., 2020).

The main focus of the present study is on respite–active music, which is applied to a high-intensity interval training (HIIT) protocol. HIIT is a highly publicised and internationally popular form of short-duration exercise that entails a series of very high-intensity (or *supramaximal*) efforts that are punctuated by recovery periods (Niven et al., 2021). An accumulating body of scientific work (e.g., Campbell et al., 2019; Collins et al., 2023) suggests that several weeks of HIIT can engender physical health benefits that are comparable to those derived from long-duration, aerobic-type exercise. This body of work is not without its detractors (e.g., Ekkekakis & Tiller, 2023), who have suggested that many of the experimental protocols *as executed* do not meet the physiological criteria for high-intensity exercise (i.e., participants' HRs suggest that they are exercising at only a moderate intensity), and are characterised by *p*-hacking (e.g., cherry-picking statistically significant findings for reporting purposes). Perhaps the harshest and most loudly amplified criticism of HIIT is that it is such an unpleasant form of exercise that it serves to undermine people's best intentions to remain physically active (Ekkekakis et al., 2020; Rhodes et al., 2022). Attitudes and intentions towards HIIT (see Stork et al., 2017) will be measured before and after the experiment reported herein.

Given the potential health benefits of HIIT, its global popularity and the high likelihood that exercisers will find it an ostensibly unpleasant activity, there is research interest in environmental manipulations that might ameliorate the negative psychological and psychophysical responses that it engenders (Jones et al., 2020; Karageorghis et al., 2021). Such responses include affective decline, bad affective memories, motivation slumps, low enjoyment levels, high ratings of perceived exertion and a tendency towards *association* (i.e., a focus on internal, task-relevant cues; see Hutchinson & Karageorghis, 2013). Because music is an inexpensive, low friction, easy to administer and ecologically valid form of environmental manipulation, it has attracted the attention of a number of researchers (e.g., Hutchinson & O'Neil, 2020, Stork et al., 2019).

The Dual-Mode Theory of Exercise-Related Affect

Among a clutch of relevant conceptual frameworks (e.g., Rejeski's [1985] Parallel Processing Theory and Tenenbaum's [2001] model of attention as a function of exercise intensity), Ekkekakis's (2003) Dual-Mode Theory provides considerable insight regarding the relationship between exercise intensity and core affect (see also Ekkekakis et al., 2020). Assuming an adaptational perspective, the theory posits that physiological markers of ventilatory threshold (VT) and respiratory compensation point (RCP) are key turn-points for exercise-related affect. More specifically, there are homogenously positive affective responses to exercise during moderate-intensity exercise (i.e., below VT, inter-individual variability is lower). Close to VT, which denotes *heavy exercise*, there is variable affective response and so the valence dimension of core affect is amenable to external manipulation (such as through music). Beyond RCP, there are homogeneously negative affective responses, as the exerciser enters the domain of *severe exercise*, wherein there is little or no influence from cognitive processes. The active recovery phases of HIIT should, theoretically, be amenable to affect-related manipulation using a musical stimulus (see Stork et al., 2015 for a related example using sprint interval training).

Recent Studies Examining Music in HIIT-Related Protocols

The last quinquennium has witnessed the publication of three studies into active–respite music that lit the path towards the present study. First, Hutchinson and O'Neil (2020) used three independent groups (N = 45) who completed two 30-s Wingate anaerobic tests separated by 10 min of self-paced active recovery with stimulative music (Group 1), sedative music (Group 2) or a no-music control (Group 3). For Group 1, the music increased peak power from Trial 1 to Trial 2, elicited a higher mean HR during recovery, as well as higher levels of affective arousal. A couple of limitations associated with this study include a non-standardised period of active recovery, and only measuring the arousal dimension of core affect (see Ekkekakis, 2013).

Second, Jones et al. (2020) employed a within-within design in which participants (N = 18) were administered three HIIT sessions on a cycle ergometer (10 × 60 s efforts separated by 75 s recovery), with active–respite music, continuous music and a no-music control. The music manipulations had no bearing on affective valence during the supramaximal bouts or recovery periods, but the continuous music condition elicited higher scores in post-task measures of exercise enjoyment and remembered pleasure. Besides the small sample size, which was predicated on an effect size derived from an experiment into respite–passive music (i.e., music applied to static recovery; Jones et al., 2017), this study did not measure the arousal dimension of core affect (cf. Hutchinson & O'Neil, 2020). There was also no experimental condition in which the administration of music during the supramaximal efforts was followed by no music during active recovery. Moreover, experimental participants were offered a choice from two music genres (electronic dance music and grime/hip-hop), that differ considerably in their syntactic processing demands, rhythmic complexity and psycho-acoustic properties (see Karageorghis, 2017).

Third, Karageorghis et al. (2021) administered active–respite music in the form of a medium-tempo playlist, fast-tempo playlist and a no-music control for 8 × 60-s efforts on a cycle ergometer with 90-s recovery (N = 24). Similar to Jones et al. (2020), the study adopted a within-within design. The medium-tempo music enhanced affective valence during the supramaximal bouts and recovery, while both music conditions increased dissociation (only during recovery), as well as post-task exercise enjoyment and remembered pleasure. Moreover, medium-tempo music lowered the rating of perceived exertion (RPE), but HR results were inconclusive. A limitation of this study was that it did not apply any music intervention during surpramaximal exercise bouts (cf. Jones et al., 2020), and so was unrepresentative in terms of how music is often used in the field (i.e., a lack of ecological validity). A further limitation was the use of an atypical period of active recovery for HIIT (90 s), which the authors adopted to fully capitalise upon the biomusicological principle of entrainment. The present study sought to address these limitations; first, by coordinating a HIIT protocol with various combinations of in-task asynchronous music (i.e., auditory-motor synchronisation was rendered impossible during the supramaximal bouts) and active–respite music, and second, by use of a 75-s period of active recovery.

Rationale, Purpose and Hypotheses

HIIT has gained global recognition for the meaningful physical health benefits that it can confer, but exercise scientists have expressed concerns regarding the degree to which members of the general public can adhere to such an intrinsically unpleasant form of exercise (e.g., Ekkekakis & Tiller, 2023). Respite–active music is a novel form of music-related intervention (see Karageorghis, 2020), predicated on the notion that it can assuage the negative affect and high perceived exertion that are an inevitable consequence of a supramaximal exercise bout (Karageorghis et al., 2021). The use of music to enhance the experience of interval-type exercise might encourage future participation, in part, through the phenomena of affective memory and affective forecasting (see e.g., Ekkekakis et al., 2018).

There is a dearth of studies that have examined the interplay of in-task music (for a supramaximal exercise bout) and respite–active music (for a recovery period), and how these music applications influence a range of psychological (e.g., core affect), psychophysical (e.g., RPE) and psychophysiological (e.g., heart rate variability; HRV) outcomes. Moreover, such studies had not assessed key related constructs before and after experimental studies, such as exercise tolerance (see Ekkekakis et al., 2008), attitudes towards HIIT and intentions towards HIIT (see Stork & Martin Ginis, 2017). Such constructs are assessed in the present study.

The purpose of the present study was to examine the effects of respite–active music on the psychological, psychophysical and psychophysiological responses of recreationally active individuals who were administered a cycle ergometer-based HIIT-type protocol. Respite–active music was set in apposition to in-task, asynchronous music within the experimental design. The present protocol was preregistered along with the hypotheses (doi:10.5281/zenodo.10000571), which are detailed in Table 1 (see Supplementary Material 1 for a full version of this along with exploratory hypotheses).

The hypotheses are predicated on the findings of related studies (e.g., Hutchinson & O'Neil, 2020; Jones et al., 2020; Karageorghis & Jones, 2014), with particular weight given to the most closely related study (Karageorghis et al., 2021). The directional hypotheses have a primary focus on the two-way interaction of Condition × Time Point in regard to the in-task and post-task measures (see Table 1). To briefly summarise a complex array of predictions, it was expected that the fast tempo–medium tempo and no music–medium tempo conditions would elicit superior outcomes, but the pattern of differences across conditions would change in accord with time point. Specifically, the fast tempo–medium tempo condition was expected to be more effective than the other three conditions in the second half of the HIIT protocol (i.e., during the second three supramaximal exercise bouts).

Method

Study Design and Power Analysis

A partially counterbalanced, within-within-within design was used (i.e., 4 (Condition) × 2 (Stage [supramaximal exercise bout and active recovery period] × 2 (Time Point [first three and second three HIIT bouts]), with stage included for exploratory purposes. There were four conditions: (a) fast-tempo music during supramaximal exercise bouts and medium-tempo music during active-recovery periods; (b) fast-tempo music during exercise and no music during recovery; (c) no music during exercise and medium-tempo music during recovery; and (d) a no-music throughout control. Using the effect size for the active recovery, affective valence Condition × Time Point interaction reported by Karageorghis et al. (2021; $\eta_p^2 = .05/f = 0.23$), an a priori power analysis using an alpha level of .05, power at .8 and a 4 (Condition) × 2 (Time Point [first vs. second half of HIIT protocol]) design for the purpose of testing experimental hypotheses, G*Power (v. 3.1; Faul et al., 2009) indicated that a sample of 28 participants would be required to detect differences. The small telescopes approach was used to determine the smallest effect size of interest (SESOI; Simonsohn, 2015). Accordingly, the SESOI was set to the effect size that an earlier study would have had 33% power to detect (Lakens et al., 2018). The original sample size of Karageorghis et al.'s (2021) article ($N = 24$) was used as a parameter. The computation was performed using G*Power for a 4 (Condition) × 2 (Time Point) design and indicated a SESOI of $f = 0.14/d = 0.28$.

Participants

With institutional ethics approval (Ref: 43340-A-Oct/2023-47582-2), 28 participants (14 females; M_{age} 20.3 years, $SD = 1.7$ years; $M_{\text{height}} = 172.9$ cm, $SD = 10.3$ cm; M_{mass} 69.8 kg, $SD = 10.7$ kg; $M_{\text{weekly vigorous activity}}$ 202.0 min, $SD = 198.4$ min; $M_{\text{weekly moderate activity}} = 258.9$ min; $SD = 200.4$ min) were recruited using posters and flyers on a university campus, and all provided written informed consent. Four participant inclusion criteria were applied: a) aged 18–25 years; b) could fully comprehend spoken and written English; c) were sufficiently healthy to complete a HIIT protocol on several occasions; and d) participated in at least 150 min/week of moderate physical activity (PA) and/or more than 75 min/week of vigorous PA over the preceding 3 months (Bull et al., 2020).

Procedures

An overview of the study protocol is presented in Figure 1. Potential volunteers were screened to ensure they met the study inclusion criteria and determine any significant health problems that might prevent them from engaging in a HIIT protocol (e.g., a COVID–19 or flu infection). As well as a participant information sheet and consent form, the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) and 2019 Physical Activity Readiness Questionnaire for Everyone (2019 PAR-Q+; Warburton et al., 2019) were administered prior to the first laboratory visit of each participant. No significant health concerns were reported by participants, and weekly active minutes confirmed that the aforementioned inclusion criteria had been met. Details of baseline psychometric/fitness testing and protocol familiarisation can be found in Supplementary Material 2.

Experimental Trials

After a minimum of 48 hours following their pre-test familiarisation visit, the participant completed a HIIT session under four conditions: a) fast-tempo music (130–135 bpm) for the supramaximal bouts and medium-tempo music (115–120 bpm) for active recovery; b) fast-tempo music for the bouts and no music for recovery; c) no music for the bouts and medium-tempo music for recovery; and d) a no-music throughout control. Full details of music selection and delivery can be found in Supplementary Material 3. In short, the music was selected by means of a two-stage process – an initial criterion-based experimenter selection, followed by use of an independent music selection panel (N = 6) – with the goal of optimising the playlists for HIIT, while affording due consideration to experimental participants' demographic profile and cultural background (cf. Karageorghis et al., 2021). Experimental participants were not involved in music selection to avoid several threats to internal validity that can be posed by such an approach (see e.g., Terry et al., 2020).

The study was delimited to four of nine potential orders of presentation (i.e., of fast-tempo music, medium-tempo music and a no-music control) so as to render the experiment manageable for the experimenters and experimental participants. The chosen conditions focus on the comparisons that, on theoretical grounds (see Karageorghis, 2016; Karageorghis et al., 2021), are of most interest. Each participant was instructed to maintain their typical habits in terms of both sleep and diet. They were also requested to desist from any other form of physical activity for the entire day when a visit to the laboratory was due. The four HIIT test conditions were administered ~48–72 hours apart.

Each participant's HR/HRV was recorded throughout by use of a chest-strap transmitter linked to a wristwatch (Polar H10; Polar Electro Oy, Kempele, Finland). Using the transmitter, we recorded supramaximal exercise bout peak and average HR values, as well as recovery low and average values recorded for each HIIT stage. In terms of HRV, we recorded the RR intervals from which the root mean square of successive RR interval differences (RMSSD), and the standard deviation of normal-to-normal RR intervals (SDNN) were extracted. Six HIIT stages were included, each with an exercise bout and an ensuing period of active recovery.

The HIIT session comprised a 2-min warm-up at 50 W followed immediately by the first 60-s supramaximal exercise bout (100% Wmax) at 80 rpm. The exercise bout was followed by a 75-s recovery period at 50 W, wherein the participant continued to cycle at 70 ± 2 rpm. A further five exercise bouts were completed, each separated by a 75-s period of active recovery. Following the final bout, the participant completed a 75-s recovery period at 50 W and then dismounted the cycle ergometer. Each participant was scheduled at the same time of day for their experimental and control trials, in order to reduce diurnal variation in HIIT performance (see e.g., Chtourou & Souissi, 2012; Drust et al., 2005).

The participant was prompted to report RPE, state attention, FS, FAS and state motivation in the first and last 15 s of each active recovery period. Music was never played in the first 15 s of each recovery period in order that responses to supramaximal exercise were not contaminated by active–respite music. Remembered pleasure and perceived enjoyment were reported immediately following cool-down. At the end of the fifth visit to the laboratory, the participant was re-administered the PRETIE-Q, as well as the attitudes and intentions towards HIIT items. Each participant was also administered a music liking item (see Karageorghis & Jones, 2014) to assess equivalence across the two playlists (fast- and medium-tempo) administered in the experimental conditions. This item was administered with reference to use of the music in a HIIT protocol. Finally, the participant was asked a series of eight open-ended questions as a form of manipulation check to evaluate their perception of differences in the audio content across conditions. The questions also led to a deeper understanding of individual responses to the experimental manipulations.

Data Analysis

Following data screening and checks for parametric assumptions (i.e., normality and homoscedasticity), differences in theoretically linked dependent variables (i.e., affective valence and arousal) measured over time were analysed by means of three-way 4 (Condition) × 2 (Stage) × 2 (Time Point) MANCOVA. A priori hypotheses were predicated on the two-way interaction of Condition × Time Point (see Table 1). In the MANCOVA, the difference scores from pre- to post-experiment from the Tolerance scale of the PRETIE-Q were used as a covariate (i.e., $\text{Tolerance}_{\text{diff}}$), following checks for the relevant covariate assumptions (e.g., linearity and homogeneity of regression slopes; see Tabachnick & Fidell, 2018). RPE, state attention and state motivation were analysed by means of three-way 4 (Condition) × 2 (Stage) × 2 (Time Point) AN(C)OVAs. For these analyses, $\text{Tolerance}_{\text{diff}}$ was also used as a covariate where the covariate assumptions were met (i.e., for RPE and state attention).

HR and HRV data were analysed by means of three-way 4 (Condition) × 2 (Stage) × 6 (Time) (M)ANOVAs, in which time points were not averaged to allow us to analyse the time series with precision. Differences in remembered pleasure and exercise enjoyment were analysed by means of one-way, repeated-measures (RM) ANCOVAs. Music liking differences were analysed using a TOST procedure ($d_{\text{SESOI}} = 0.28$; Lakens et al., 2018). Differences in pre-/post-experiment scores from the Attitudes and Intentions Towards HIIT questionnaire and PRETIE-Q were assessed by means of pairwise *t* tests. In all ANOVAs and MANOVAs, Greenhouse–Geisser-corrected *F* values were used in the case of sphericity violations, and Tukey post hoc tests were subject to Bonferroni adjustment. Effect sizes in the form of partial eta squared (η_p^2) are presented and, where necessary, Cohen's *d* is presented for simple effects.

Results

Details pertaining to data diagnostics are available in Supplementary Material 4. To aid interpretation of the results presented herein, inferential statistics for all dependent measures, across conditions and throughout the HIIT protocol, are provided in Table 2 (see Supplementary Material 5 for descriptive statistics).

In-Task Measures of Core Affect

Figure 3 is comprised of two spider plots containing all psychological and psychophysical in-task measures. The three-way 4 (Condition) × 2 (Stage) × 2 (Time Point) MANCOVA for core affect (valence and arousal) indicated significant omnibus statistics for stage, Pillai's Trace = 0.06, $F(2, 430) = 14.51$, $p < .001$, and time point, Pillai's Trace = 0.09, $F(2, 430) = 22.55$, $p < .001$. Stepdown *F* tests indicated main effects of stage and time point for both affective valence and arousal (see Table 2). For affective valence, post hoc tests indicated that scores were higher in the first ($M = 2.27$, $SD = 1.38$) vs. second half ($M = 1.63$, $SD = 2.11$) of the HIIT protocol ($p < .001$, $d = 0.52$), and lower in the supramaximal exercise ($M = 1.78$, $SD = 1.92$) vs. activate recovery stage ($M = 2.13$, $SD = 1.68$, $p = .042$, $d = 0.48$; see Figure 1S, Supplementary Material 6). For affective arousal, post hoc tests also indicated that scores were lower in the first ($M = 3.65$, $SD = 1.00$) vs. second half ($M = 4.15$, $SD = 1.09$) of the HIIT protocol ($p < .001$, $d = 0.66$), and higher in the supramaximal exercise ($M = 4.13$, $SD = 1.04$) vs. active recovery stage ($M = 3.67$, $SD = 1.06$, $p < .001$, $d = 0.69$).

In-Task Psychological Measures

The three-way 4 (Condition) × 2 (Stage) × 2 (Time Point) ANCOVA for RPE indicated significant main effects of stage, $F(1, 26) = 48.21$, $p < .001$, $\eta_p^2 = .65$, and time point, $F(1, 26) = 94.64$, $p < .001$, $\eta_p^2 = .78$. The two-way Stage × Time Point interaction was also significant, $F(1, 26) = 49.21$, $p < .001$, $\eta_p^2 = .65$. Post hoc tests indicated that RPE scores were higher in the first vs. second half of the HIIT protocol for both the supramaximal exercise ($M_{first} = 4.46$, $SD_{first} = 1.32$, $M_{second} = 6.46$, $SD_{second} = 1.74$, $p < .001$, $d = 1.77$) and active recovery stage ($M_{first} = 3.60$, $SD_{first} = 1.12$, $M_{second} = 4.63$, $SD_{second} = 1.50$, $p < .001$, $d = 0.94$), and that this effect was magnified in the supramaximal exercise stage (see Figure 2S, Supplementary Material 6).

The three-way 4 (Condition) × 2 (Stage) × 2 (Time Point) ANCOVA for state attention indicated significant main effects of stage, $F(1, 26) = 20.67$, $p < .001$, $\eta_p^2 = .44$, and time point, $F(1, 26) = 12.01$, $p < .001$, $\eta_p^2 = .32$. The two-way Stage × Time Point interaction was also significant, $F(1, 26) = 8.77$, $p < .001$, $\eta_p^2 = .25$. Post hoc tests indicated that state attention scores were higher in the first (*M* = 45.98, *SD* = 18.67) vs. second half (*M* = 36.19, *SD* = 22.17) of the HIIT protocol, but only in the supramaximal exercise stage ($p < .001$, $d = 0.59$; see Figure 3S, Supplementary Material 6).

The three-way 4 (Condition) × 2 (Stage) × 2 (Time Point) ANOVA for state motivation indicated a significant main effect of condition, $F(3, 81) = 2.93$, $p = .039$, $\eta_p^2 = .01$. The two-way Stage × Time Point interaction was also significant, $F(1, 27) = 5.69$, $p = .024$, $\eta_p^2 = .17$. Post hoc tests indicated that state motivation scores were higher in the fast tempo–medium tempo (*M* = 6.54, *SD* = 1.54) vs. no-music control condition (*M* = 5.91, *SD* = 1.67; $p = .036$, $d = 0.49$; see Figure 2). The post hoc tests for the Stage × Time Point interaction were non-significant (see Table 2).

In-Task Physiological Measures

The three-way 4 (Condition) × 2 (Stage) × 6 (Time Point) ANOVA for HR indicated significant main effects of stage, $F(1, 26) = 17.01$, $p < .001$, $\eta_p^2 = .40$, and time point, $F(1.56, 40.63) = 265.75$, $p < .001$, $\eta_p^2 = .91$. The two-way Stage × Time Point interaction was also significant, $F(2.98, 77.36) = 4.24$, $p < .001$, $\eta_p^2 = .14$. Post hoc tests indicated that HR values were lower at Time Points 1–2 vs. Time Points 3–6 for both the supramaximal exercise (*p*s $< .001$, *d*s > 1.14) and active recovery stage (*p*s $< .002$, *d*s > 1.01); heart-rate values were also lower at Time Point 1 vs. Time Point 2 for both stages ($p_{exercise} = .004$, $d_{exercise} = 1.87$; $p_{recovery} = .022$, $d_{recovery} = 1.75$). HR values were lower at Time Point 3 vs. Time Point 6, but only for the supramaximal exercise stage ($p = .014$, $d = 1.59$; see Figure 4S, Supplementary Material 6).

The three-way 4 (Condition) × 2 (Stage) × 6 (Time Point) MANOVA for HRV (RMSSD and SDNN) indicated significant omnibus statistics for the main effects of condition, Pillai's Trace = 0.02, $F(6, 2400) = 4.35$, $p < .001$, stage, Pillai's Trace = 0.07, $F(2, 1199) = 47.32$, $p < .001$, and time point, Pillai's Trace = 0.22, $F(10, 2400) = 29.53$, $p < .001$. The two-way Stage × Time Point interaction was also significant, Pillai's Trace = 0.03, $F(10, 2400) = 4.18$, $p < .001$. Stepdown *F* tests indicated main effects of stage and time point, and a significant Stage × Time Point interaction for RMSSD; and main effects of condition, stage, and time point for SDNN (see Table 2). For RMSSD, post hoc tests indicated that values were higher at Time Point 1 vs. Time Points 2–6, but only in the active-recovery stage (*p*s < .001, *d*s > 0.75; see Figure 5S, Supplementary Material 6). For SDNN, post hoc tests indicated lower values in the fast tempo–no music ($M = 3.21$, $SD = 1.42$) vs. no music–no music condition ($M = 3.66$, $SD = 1.91$, $p = .007$, $d = 0.32$); values were also lower in the supramaximal exercise ($M = 2.30$, $SD = 1.36$) vs. active recovery stage ($M = 3.81$, $SD = 1.97$, $p < .001$, $d = 0.60$). Moreover, SSDN values were higher at Time Points 1–2 vs. Time Points 3–6 (*p*s < .039, *d*s > 0.44); SSDN values were also lower at Time Point 1 vs. 2 ($p < .001$, $d = 0.83$), and at Time Point 3 vs. Time Point 6 ($p < .001$, $d = 0.61$; see Figure 6S, Supplementary Material 6).

Post-Task and Pre-/Post-Experiment Psychological Measures

One-way RM ANOVAs for remembered pleasure and exercise enjoyment were non-significant (see Table 2). The pairwise *t* test for exercise tolerance was significant, $t(28) = 5.02$, $p < .001$, $d = 0.95$, indicating that exercise-tolerance scores were lower prior to the experiment ($M = 25.29$, $SD = 5.83$) when compared to the immediate end of the experiment ($M = 29.36$, $SD = 6.06$; see Figure 7S, Supplementary Material 6). The pairwise *t* test for attitudes towards HIIT was non-significant, $t(28) = 1.91$, $p = .067$, $d = 0.36$, as was the *t* test for intentions towards HIIT, $t(28) = 1.80$, $p = .083$, $d = 0.34$.

Music Liking

The TOST procedure applied to music-liking scores did not reach significance, $t_{upper}(27) = 4.34$, $p < .001$, $t_{lower}(27) = 1.74$, $p = .954$. Accordingly, a pairwise *t* test was used to assess the difference in music liking between the fast- and medium-tempo playlist. The *t* test was significant, $t(28) = 3.04$, $p = .005$, $d = 0.57$, indicating that music-liking scores were higher for the fast-tempo playlist (*M* = 7.57, *SD* = 2.15) when compared to the medium-tempo playlist (*M* = 6.11, *SD* = 2.25; see Figure 8S, Supplementary Material 6). Details of the manipulation check can be found in Supplementary Material 7.

Discussion

The main purpose of this study was to investigate the effects of in-task asynchronous music and respite–active music on psychological, psychophysical and psychophysiological responses both during and immediately after a six-stage HIIT protocol. None of the research hypotheses (H_1–H_8; see Table 1) is supported by the present data. A primary task of this section will be to explore *why* that is, but also the possible reasons for which the present findings are at odds with those of closely related studies (e.g., Hutchinson & O'Neil, 2020; Jones et al., 2017; Karageorghis et al., 2021).

With reference to the exploratory hypotheses (E_1–E_5; see Supplementary Material 1), with the exception of the lower SDNN values found in the fast tempo–no music condition when compared to the no music–no music control (E_2; see Figure 6S, Supplementary Material 7), none of the statistical tests indicated that the music-related manipulations had any effect on the range of outcomes. However, the test of E_3, which explored how participation in a HIIT-related experiment influenced exercise tolerance (measured using the PRETIE-Q), indicated that tolerance scores increased from pre- to post-experiment ($p < .001$; $d = .95$; see Figure 7S, Supplementary Material 7). This observation led us to enter $\text{Tolerance}_{\text{diff}}$ as a covariate in all analyses in which this variable met the required assumptions (see Tabachnick & Fidell, 2018). Participation in this HIIT-related experiment had no bearing on attitudes towards HIIT or intentions towards HIIT (see Supplementary Material 5). The equivalence test for music liking (under H_8) indicated a lack of equivalence, and that the fast-tempo condition elicited higher scores than the medium-tempo condition (see Figure 8S, Supplementary Material 6).

Having established that the music manipulations had little effect across the range of dependent variables, it did transpire that for four of the in-task measures, the first half of the six-stage HIIT protocol elicited more positive scores than the second half (i.e., there was a main effect of time point). Specifically, affective valence scores were significantly ($p < .001$) higher in the first vs. the second half. Affective arousal scores were significantly ($p < .001$) lower in the first half vs. the second, as were RPE scores ($p < .001$). Moreover, state attention scores were significantly ($p < .001$) higher in the first vs. the second half, indicative of greater dissociation in the early part of the HIIT protocol. These main effects are, however, disinteresting from a theoretical standpoint (e.g., Ekkekakis, 2003; Rejeski, 1985).

In-Task Psychological and Psychophysical Measures

The core affect data (see Table 2) indicated that both in-task and respite–active music manipulations were ineffectual in assuaging the affective decline that typifies HIIT (Box et al., 2020). It is unusual in this enclave of the exercise psychology literature for a music manipulation not to have any bearing on exercise-related affect (see e.g., Hutchinson & O'Neil, 2020; Jones et al., 2017). Moreover, the present findings are at odds with those of a preceding study (Karageorghis et al., 2021), which showed that a medium tempo, active–respite condition elicited superior affective valence scores when compared to fast-tempo music and a no-music control during exercise bouts and active recovery (i.e., a main effect of condition). The in-task findings for affective valence of Jones et al. (2020) were, however, similar to those of the present study.

Considering the present findings alongside those of Jones et al. (2020) with reference to relevant theory, Ekkekakis' (2003) Dual Mode Theory posits that beyond the respiratory compensation point (i.e., the *severe* exercise intensity domain), exercise-related affect is universally negative, and not amenable to manipulation. Accordingly, although the present findings deviate somewhat from closely related findings in the exercise psychology literature (e.g., Jones et al., 2017; Karageorghis et al., 2021), they do frank the implication of Dual Mode Theory that a music intervention is unlikely to assuage affective decline during supramaximal exercise. This is a key theoretical contribution of the present study, given a welter of evidence that has suggested the converse, often with exercise tasks in which intensity was not fully standardised (e.g., Boutcher & Trenske, 1990; Hutchinson et al., 2011; Karageorghis et al., 2009).

Along similar lines to the core affect findings, the music manipulations had no bearing on RPE or state attention scores (see Figure 3). One possibility is that the in-task use of fast-tempo music drove participants to work slightly harder than in the Karageorghis et al. (2021) study, in which only respite–active music was administered. This suggestion is predicated on a comparison of exercise HR data from the present study with that derived from the 2021 study (see Figure 4S, Supplementary Material 6). Specifically, participants in the present study recorded a higher percentage of their maximal HR in the no music–medium tempo condition, regardless of stage, when compared to the 2021 study. When examining the self-reported weekly levels of vigorous and moderate physical activity between the present and 2021 study, it is clear that the present participants engaged in *much* higher levels at both intensities. The superior activity levels of the present participants appear to have predisposed them to adhering strictly to the experimental HIIT protocol. Although the rpm was fixed for both supramaximal exercise bouts (80 rpm) and active recovery periods (70 rpm), using a three-way ANOVA, we checked whether the music conditions had any bearing on rpm (i.e., whether rpm was slightly higher with in-task fast-tempo music). There was no main effect of condition ($p < .05$), which again suggests good adherence to the study protocol.

Only state motivation was influenced by the music manipulation, with the fast tempo–medium tempo condition eliciting higher scores than the no-music control in both interval and active recovery stages, and across both halves of the HIIT protocol (see Figure 2). There is a sizeable literature supporting the use of music for motivation – even in high-intensity tasks (e.g., Karageorghis et al., 2013; Stork et al., 2019) – with associated neurophysiological evidence implicating stimulation of the ascending reticular activating system (e.g., Kim et al., 2023). The benefits for state motivation, however, are not reflected in other in-task measures, or in post-task measures (see Supplementary Material 6). There is a trend towards higher affective valence scores for fast tempo–medium tempo, but this did not reach significance (see Supplementary File 5).

The lack of effect for psychological and psychophysical measures can be understood with reference to a range of neurophysiological mechanisms. First, there is involuntary attentional switching – from dissociation to association – that occurs at high exercise intensities (see e.g., Karageorghis & Jones, 2014), caused by the (attentionally) overbearing strength of signals transmitted through the afferent nervous system (Rejeski, 1985). Second, at high intensities, auditory stimuli are ineffective in limiting the neuronal communication across somatosensory regions of the brain (e.g., the central and frontal regions; see e.g., Bigliassi et al., 2017). Third, the transition from oxygenated to deoxygenated haemoglobin in the dorsolateral prefrontal cortex, when the exerciser nears physical exhaustion, has profound consequences for exercise-related affect (i.e., the exercise feels *very bad*; Bigliassi & Filho, 2022). In addition to such neurophysiological explanations, there is also the possibility that in some of the related studies (e.g., Jones et al., 2017; Karageorghis et al., 2021), participants did not exert themselves to the same degree as those in the present study (see Supplementary Material 8 for a direct comparison with Karageorghis et al., 2021).

The difference in the pattern of response between RPE and state attention supports the notion that these measures are not phenomenologically isomorphic (Razon et al., 2012). The significant ($p < .001$) Stage × Time interaction for RPE, indicated that, as expected, RPE scores were much higher during supramaximal exercise than active recovery, and also higher during the second half of the protocol vs. the first half (see Figure 2S in Supplementary Material 6). Nonetheless, there was far great heterogeneity in RPE responses in the second half of the protocol, particularly during active recovery. Such heterogeneity suggests that there is greater scope for attentional manipulation using a stimulus such as music (cf. Ekekkakis', 2003, Dual-Mode Theory). The state attention findings indicated a different pattern in the significant ($p < .001$) State × Time Point interaction when compared to RPE. Specifically, there was a tendency towards greater association in the second half of the HIIT protocol, but only in the supramaximal exercise stage.

Post-Task Psychological Measures

Somewhat surprisingly, results from the remembered pleasure item show that the music manipulations were ineffectual (see Table 2). Similarly, results for exercise enjoyment, as measured by PACES, show that the manipulations were ineffectual. In a related study

(Karageorghis et al., 2021), PACES scores provided the most defined differentiation across conditions. Moreover, remembered pleasure scores were higher in each of the two music conditions when compared to control. In the Jones et al. (2020) study, music throughout the HIIT protocol elicited higher scores for PACES and remembered pleasure. It might be deduced from the present post-task measures – particularly when considered in light of the in-task measures – that the gestalt experience of HIIT was *so* unpleasant, that no in-task musical manipulation could positively influence post hoc perceptions. This applies in equal measure to attitudes towards HIIT and intention towards HIIT (see Table 2).

The implication of these findings is that the music manipulations did not enhance the valence associated with participants' recall of a high-intensity exercise protocol. The post-task outcomes are unlike those reported in related studies (Jones et al., 2020; Karageorghis et al., 2021; Stork et al., 2019). The finding pertaining to remembered pleasure and exercise enjoyment is important from an applied perspective, because if a goal of exercise science is to encourage the general population to be habitually active (see e.g., Milton et al., 2023), affective memories are a central consideration (Ekkekakis et al., 2018; Rhodes & Kates, 2015). A select few exercisers will tolerate, endure and maybe even claim to enjoy supramaximal routines such as HIIT (see Box & Petruzzello, 2020), but for the vast majority of people who exercise, such routines can prove problematic in terms of promoting their long-term participation (Ekkekakis et al., 2020). Our tests of E_4 and E_5 show how participation in five HIIT-related sessions (inc. familiarisation) improved neither attitudes nor intentions towards HIIT, which has direct implications for future volitional exercise behaviours that involve HIIT or related protocols.

Heart Rate (HR) and Heart Rate Variability (HRV) Data

The higher-order Condition × Stage × Time Point interaction was non-significant ($p < .05$), but a significant ($p < .001$) two-way interaction of Stage × Time Point did emerge (see Table 2). This indicated that increases and decreases in HR were in the expected direction for a HIIT Protocol (see Figure 4S, Supplementary Material 6) and an examination of the associated means (see Supplementary Material 5) suggests that, on the whole, participants worked sufficiently hard during supramaximal exercise to elevate HR close to their age-predicted max. HR therefore served a useful purpose as a form of physiological manipulation check and franks the notion that participants were going "all out" during the supramaximal exercise bouts. At the intensities associated with the present protocol, the biomusicological principle of entrainment (see Terry et al., 2020) had no discernible bearing, and thus the music manipulations did not appear to either upregulate or downregulate HR.

We took a multivariate approach to analysing HRV indices and although condition had no bearing on RMSSD, it did on SDNN (see Figure 5S and Figure 6S, Supplementary Material 6). Specifically, mean SDNN scores were lower in the fast tempo–no music condition than in the no music–no music control ($d = 0.32$; see Supplementary Material 5). The effect was small but hints at the potentially deleterious effect of removing music for the active recovery stage after it is presented for supramaximal exercise (cf. Stork et al., 2019). SDNN is an index of total variability in HR (Laborde et al., 2022), and so this finding suggests greater physiological activation in the presence of music. There is a possibility of a successive contrast effect, but given the objective nature of SDNN, coupled with the fact that a similar drop did not emerge in the fast tempo–medium tempo or no music–medium tempo conditions, suggests that the removal of music for active recovery is counterindicated by the present findings.

Strengths and Limitations

This is the first study to examine a combination of active–respite music with in-task asynchronous music during a HIIT protocol, and thus clearly extends previous work (e.g., Jones et al., 2017, 2020; Karageorghis et al., 2021). Given the use of a counterbalanced experimental design and an array of both subjective (e.g., core affect) and objective (e.g., HRV) measures, the findings offer some practical utility. The protocol, associated hypotheses and analyses were preregistered (with zenodo.com) – a process that is considered to improve the quality and transparency of research (Hagger, 2022). Moreover, the SESOI was used to ensure that, for each statistical test, a true effect exists where significant differences were found (see Lakens et al., 2018). For each significant statistical test, the effect sizes were larger than the required SESOI (i.e., $d = 0.28$), indicating that the effects were sufficiently strong to yield meaningful results.

Exercise tolerance was measured using the PRETIE-Q (Ekkekakis et al., 2008), both before and after the experiment, with the $\text{Tolerance}_{\text{diff}}$ scores used as a covariate in the analyses. A post-experiment manipulation check indicated that 18 out of 28 participants were able to correctly identify that there were different configurations of music across the four conditions. In regard to the choice of music, the experiment was strengthened by a panel-based music selection procedure that entailed use of contemporary popular music (i.e., relevant to the young adult participants) that was professionally edited. To avoid potential biases (see Terry et al., 2020), the experimental participants had no part in the music-selection procedure, and only rated the music programme after their final experimental trial.

The present study was not, however, without some limitations. When compared to the most closely related study (Karageorghis et al., 2021), this study employed a shorter period of active recovery (75 s vs. 90 s), as well as a shorter excerpt of respite–active music (60 s vs. 75 s). This hints at the possibility that the duration of respite–active music was insufficient for the biomusicological principle of entrainment to take full effect (see Terry et al., 2020). Moreover, the music appeared to have a generalised stimulative effect on HR, which although not reaching statistical significance, was slightly higher throughout the HIIT protocol when music was present (see Figure 4S, Supplementary Material 6; cf. Stork et al., 2019). Accordingly, it is difficult to ascertain whether the presence of music (in-task or respite–active) led to slightly higher effort levels or elevated HR through a direct influence on the neural system (cf. Karageorghis et al., 2018).

The test of H_8, which focused on equivalence in music-liking scores between the medium- and fast-tempo music conditions, indicated non-equivalence (see Figure 8S, Supplementary Material 6). This presents a threat to internal validity, but equivalence could only have been ensured through involving experimental participants in music selection. Such an approach, however, presents its own threats to internal validity; primarily through creating fertile ground for Hawthorne and experimenter effects (see Terry et al., 2020). The threat posed by the lack of equivalence is assuaged somewhat by the fact that medium-tempo music was only used for active recovery, and fast-tempo music was only used for supramaximal exercise bouts. The highest mean-liking scores were for the fast-tempo music ($M_{\text{fast tempo}}$ = 7.57 vs. $M_{\text{medium tempo}}$ = 6.10), which might reflect a general preference for music during the most physically demanding segments of the HIIT protocol. In the manipulation check, it was surprising that only two participants recognised that it was the tempo component of music that was being manipulated. Clearly, for the most part, participants could not discern, in terms of tempo at least, the differences between the two playlists.

Implications for Practice

The past decade has witnessed a lively debate in the exercise psychology literature regarding high-intensity exercise regimens. Specifically, whether much-touted formats, such as HIIT, can do anything to counter the rising tide of sedentariness in the developed world (see Ekkekakis & Tiller, 2023). Some scholars have suggested that the promotion of HIIT might even be counterproductive from a public health perspective (Ekkekakis et al., 2020). At the core of the debate is the notion of *exercise hedonics*, or how the pleasure derived from an exercise routine might promote habitual exercise behaviours (Evmenenko & Teixeira, 2022). The main implication of the present findings is that even with three carefully constituted music manipulations, HIIT was an unpleasant experience and also remembered as such (see Table 2). Findings relating to the SDNN index from the HRV data suggest that if music is used for supramaximal exercise, it should not be removed for an ensuing period of active recovery (see Figure 6S, Supplementary Material 6).

If HIIT essentially leads to an unpleasant exercise experience – even with a tailored/age-appropriate music programme – does that mean that it should not be promoted at all? Well, there are clear physiological benefits that can be derived from HIIT (Collins et al., 2023), the benefits cut across age groups (Campbell et al., 2019), and some people *can* adhere to it (Ekkekakis & Biddle, 2023). Nonetheless, for the vast majority of people, many of whom appear to struggle to engage in daily exercise, HIIT is certainly not the "magic bullet" that its advocates might like to suggest. The affective and perceptual responses to

HIIT are not amenable to manipulation from musical stimuli, as demonstrated in the present study, and as demonstrated, in part, by a related study (Jones et al., 2020).

The present findings combined with related findings suggest at least four music applications that would work for individuals who have the tolerance and preference for HIIT-type protocols. First, the use of music throughout HIIT is likely to elevate state motivation and power output (cf. Stork et al., 2019 who studied sprint interval training; SIT). Second, the use of fast-tempo music throughout HIIT can elevate post-task enjoyment and remembered pleasure (Jones et al., 2020). Third, to assuage the negative exercise-related affect that is induced by supramaximal bouts during HIIT, the use of medium-tempo music during active recovery *only* should be considered, but for a duration of 75–90 s to give sufficient time for entrainment to take effect (see Karageorghis et al., 2021). Fourth, slow-tempo music should be avoided during HIIT recovery periods, as it is likely to downregulate affective arousal and compromise subsequent supramaximal efforts (Hutchinson & O'Neil, 2020).

Recommendations for Future Research

A clear first step in terms of furthering this line of investigation entails testing the five potential orders of fast-tempo music, medium-tempo music and no music that were not tested in the present study. This would provide useful information regarding whether tempo manipulation per se has any bearing on responses, because three of the conditions would be: fast tempo–fast tempo, medium tempo–medium tempo and the counterintuitive medium tempo–fast tempo – counterintuitive because the least auditory stimulation would be presented during the supramaximal exercise stage. A second step would entail adopting a similar design with an extension of the active recovery period to 90 s, in order to fully capitalise upon the biomusicological principle of entrainment (cf. Karageorghis et al., 2021).

Taking a broader perspective, it would be worthwhile to explore individual difference factors in such a protocol. Among the foremost candidates would be exercise tolerance, the extroversion–introversion dimension of personality and the association–dissociation dimension of trait attention (cf. Hutchinson & Karageorghis, 2013). Albeit the present study focused on participants who exercised individually, there may be additional learnings to be gleaned from the application of HIIT-related protocols in a group exercise context. For example, the phenomena of *emotional contagion* or *shared affective motion experience* (SAME; see Terry et al., 2020) might emerge. The former entails a spontaneous spread of emotions and related behaviours (e.g., rhythmic movement) in response to music, and the latter is manifested when exercisers sense the musical rhythm through others moving in time in their vicinity, and enjoy the sensation of functioning as a collective.

Future researchers might examine hedonic interventions, such as respite–active music, over several months to further understanding of the link between exercise-related affect and exercise behaviours. There is a conspicuous dearth of such work in the exercise psychology literature (see e.g., Terry et al., 2020). Moreover, given the novel finding to emerge from the HRV index of SDNN, suggesting that the removal of music can cause physiological distress, this is certainly an aspect that warrants further investigation. For example, when music is removed during bouts of continuous low- or moderate-intensity exercise, is there a corresponding decrease in the total variability in HR?

Conclusions

The present findings are generally atypical of the findings that emerge from studies that examine how audio-visual manipulations influence the exercise experience (e.g., Jones et al., 2017; Stork et al., 2019). The four types of music manipulation that were administered during a six-stage HIIT protocol (fast tempo–medium tempo, fast tempo–no music, no music–medium tempo and no music–no music) had little bearing on a range of subjective and objective measures (see Table 2). Analyses of the in-task measures indicated that the second half of the HIIT protocol was physiologically more demanding than the first, and also perceived more negatively, but this is unsurprising and not of theoretical interest. We explored the reasons for a lack of effect and, chief among these were: (a) even though exercise intensity was predetermined, the use of in-task music caused participants to work *slightly harder* during the supramaximal exercise bouts when compared to the no music–no music control (see Figure 4S, Supplementary Material 6; cf. Stork et al., 2015), and so indices taken during active recovery and immediately after the HIIT protocol could have been confounded by workload; (b) the period over which participants were exposed to respite–active music (60 s) was shorter than in related studies (e.g., Hutchinson & O'Neil, 2020; Karageorghis et al., 2021); and (c) post-experiment liking scores for the two music conditions were not invariant, with fast-tempo eliciting significantly (p = .005) higher scores than the medium-tempo condition.

Among the batch of related studies, the present study was particularly well controlled with careful attention afforded to construction of the playlists (not confounded by experimental participant selections as in many related studies; see Terry et al., 2020), a task-relevant pre-test to establish experimental workload, and a thorough familiarisation procedure. When the present findings are examined against the backdrop of related findings, the main practical recommendation to emerge is that if a music programme is used for HIIT-type protocols with the intention of enhancing the exercise experience (but not to maximise work output), only respite–active music should be used (i.e., during recovery), and its duration should be 75–90 s (Karageorghis et al., 2021). The interoceptive cues associated with supramaximal exercise serve to diminish the psychological and psychophysical effects of music (cf. Ekkekakis' 2003 Dual Mode Theory), even though perceptions of state motivation can be enhanced (see Figure 2). The latter finding prompts a secondary practical recommendation, which is that if music is applied to HIIT-type protocols as a motivational tool, it seems that its sequential use in asynchronous and respite–active modes can be efficacious (i.e., fast-tempo music for supramaximal bouts, followed by medium-tempo music for active recovery).

References

Bigliassi, M. & Filho, E. (2022). Functional significance of the dorsolateral prefrontal cortex during exhaustive exercise. *Biological Psychology*, *175,* Article 108442. https://doi.org/10.1016/j.biopsycho.2022.108442

Bigliassi, M., Karageorghis, C. I., Wright, M. J., Orgs, G., & Nowicky, A. V. (2017). Effects of auditory stimuli on electrical activity in the brain during cycle ergometry. *Physiology & Behavior*, *177*, 135–147. https://doi.org/10.1016/j.physbeh.2017.04.023

Boutcher, S. H., & Trenske, M. (1990). The effects of sensory deprivation and music on perceived exertion and affect during exercise. *Journal of Sport & Exercise Psychology*, *12*(2), 167–176. https://doi.org/10.1123/jsep.12.2.167

Box, A. G., Feito, Y., Zenko, Z., & Petruzzello, S. J. (2020). The affective interval: An investigation of the peaks and valleys during high-and moderate-intensity interval exercise in regular exercisers. *Psychology of Sport and Exercise, 49*, Article e101686. https://doi.org/10.1016/j.psychsport.2020.101686

Box, A. G., & Petruzzello, S. J. (2020). Why do they do it? Differences in high-intensity exercise-affect between those with higher and lower intensity preference and tolerance. *Psychology of Sport and Exercise*, *47*, Article e101521. https://doi.org/10.1016/j.psychsport.2019.04.011

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., Lambert, E., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451–1462. https://doi.org/10.1136/bjsports-2020-102955

Campbell, W. W., Kraus, W. E., Powell, K. E., Haskell, W. L., Janz, K. F., Jakicic, J. M., Troiano, R. P., Sprow, K., Torres, A., Piercy, K. L., Bartlett, D. B. (2019). High-intensity interval training for cardiometabolic disease prevention. *Medicine & Science in Sports & Exercise*, *51*(6), 1220–1226. https://doi.org/10.1249/MSS.0000000000001934

Chtourou, H., & Souissi, N. (2012). The effect of training at a specific time of day: A review. *The Journal of Strength & Conditioning Research*, *26*(7), 1984–2005. https://doi.org/10.1519/JSC.0b013e31825770a7

Collins, B. E. G., Donges, C., Robergs, R., Cooper, J., Sweeney, K., & Kingsley, M. (2023). Moderate continuous- and high-intensity interval training elicit comparable cardiovascular effect among middle-aged men regardless of recovery mode. *European Journal of Sport Science*, *23*(8), 1612–1621. https://doi.org/10.1080/17461391.2023.2171908

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Drust, B., Waterhouse, J., Atkinson, G., Edwards, B., & Reilly, T. (2005). Circadian rhythms in sports performance—an update. *Chronobiology International*, *22*(1), 21–44. https://doi.org/10.1081/cbi-200041039

Ekkekakis, P. (2003). Pleasure and displeasure from the body: Perspectives from exercise. *Cognition and emotion*, *17*(2), 213–239. https://doi.org/10.1080/02699930302292

Ekkekakis, P. (2013). *The measurement of affect, mood, and emotion: A guide for health-behavioral research*. Cambridge University Press. https://doi.org/10.1017/CBO9780511820724

Ekkekakis, P., & Biddle, S. J. H. (2023). Extraordinary claims in the literature on high-intensity interval training (HIIT): IV. Is HIIT associated with higher long-term exercise adherence?. *Psychology of Sport and Exercise*, *64*, Article e102295. https://doi.org/10.1016/j.psychsport.2022.102295

Ekkekakis, P., Hartman, M. E., & Ladwig, M. A. (2020). Affective responses to exercise. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of sport psychology* (4th ed., pp. 233–253). Wiley. https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119568124.ch12

Ekkekakis, P., Thome, J., Petruzzello, S. J., & Hall, E. E. (2008). The Preference for and Tolerance of the Intensity of Exercise Questionnaire: A psychometric evaluation among college women. *Journal of Sports Sciences*, *26*(5), 499–510. https://doi.org/10.1080/02640410701624523

Ekkekakis, P., & Tiller, N. B. (2023). Extraordinary claims in the literature on high-intensity interval training: II. Are the extraordinary claims supported by extraordinary evidence? *Kinesiology Review*, *12*(2), 144–157. https://doi.org/10.1123/kr.2022-0003

Ekkekakis, P., Zenko, Z., Ladwig, M. A., & Hartman, M. E. (2018). Affect as a potential determinant of physical activity and exercise: Clinical appraisal of an emerging research field. In D. Williams, R. Rhodes, & M. Conner (Eds.), *Affective determinants of health behavior* (pp. 237–239), Oxford University Press. https://doi.org/10.1093/oso/9780190499037.003.0011

Evmenenko, A., & Teixeira, D. S. (2022). The circumplex model of affect in physical activity contexts: A systematic review. *International Journal of Sport and Exercise Psychology*, *20*(1), 168–201. https://doi.org/10.1080/1612197X.2020.1854818

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Hagger, M. S. (2022). Developing an open science 'mindset'. *Health Psychology and Behavioral Medicine*, *10*(1), 1–21. https://doi.org/10.1080/21642850.2021.2012474

Hutchinson, J. C., Jones, L., Vitti, S. N., Moore, A., Dalton, P. C., & O'Neil, B. J. (2018). The influence of self-selected music on affect-regulated exercise intensity and remembered pleasure during treadmill running. *Sport, Exercise, and Performance Psychology*, *7*(1), 80–92. https://doi.org/10.1037/spy0000115

Hutchinson, J. C., & Karageorghis, C. I. (2013). Moderating influence of dominant attentional style and exercise intensity on responses to asynchronous music. *Journal of Sport & Exercise Psychology*, *35*(6), 625–643. https://doi.org/10.1123/jsep.35.6.625

Hutchinson, J. C., & O'Neil, B. J. (2020). Effects of respite music during recovery between bouts of intense exercise. *Sport, Exercise, and Performance Psychology*, *9*(1), 102–114. https://doi.org/10.1037/spy0000161

Hutchinson, J. C., Sherman, T., Davis, L., Cawthon, D., Reeder, N. B., & Tenenbaum, G. (2011). The influence of asynchronous motivational music on a supramaximal exercise bout. *International Journal of Sport Psychology*, *42*(2), 135–148.

Jones, L., Stork, M. J., & Oliver, L. S. (2020). Affective responses to high-intensity interval training with continuous and respite music. *Journal of Sports Sciences*, *38*(24), 2803–2810. https://doi.org/10.1080/02640414.2020.1801324

Jones, L., Tiller, N. B., & Karageorghis, C. I. (2017). Psychophysiological effects of music on acute recovery from high-intensity interval training. *Physiology & Behavior*, *170*, 106–114. https://doi.org/10.1016/j.physbeh.2016.12.017

Jia, T., Ogawa, Y., Miura, M., Ito, O., & Kohzuki, M. (2016). Music attenuated a decrease in parasympathetic nervous system activity after exercise. *PloS one*, *11*(2), Article e0148648. https://doi.org/10.1371/journal.pone.0148648

Jing, L., & Xudong, W. (2008). Evaluation on the effects of relaxing music on the recovery from aerobic exercise-induced fatigue. *Journal of Sports Medicine and Physical Fitness*, 48(1), 102–106. https://pubmed.ncbi.nlm.nih.gov/18212717/

Karageorghis, C. I. (2016). The scientific application of music in exercise and sport: Towards a new theoretical model. In A. M. Lane (Ed.), *Sport and exercise psychology* (2nd ed., pp. 274–320). Taylor & Francis. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315713809-15/scientific-application-music-exercise-sport-costas-karageorghis

Karageorghis, C. I. (2017). *Applying music in exercise and sport*. Human Kinetics.

Karageorghis, C. I. (2020). Music-related interventions in sport and exercise. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of sport psychology* (4th ed., pp. 929–949). Wiley. https://doi.org/10.1002/9781119568124.ch45

Karageorghis, C. I., Bruce, A. C., Pottratz, S. T., Stevens, R. C., Bigliassi, M., & Hamer, M. (2018). Psychological and psychophysiological effects of recuperative music postexercise. *Medicine & Science in Sports & Exercise, 50*, 739–746. https://doi.org/10.1249/MSS.0000000000001497

Karageorghis, C. I., & Jones, L. (2014). On the stability and relevance of the exercise heart rate–music-tempo preference relationship. *Psychology of Sport and Exercise*, *15*(3), 299–310. https://doi.org/10.1016/j.psychsport.2013.08.004

Karageorghis, C. I., Jones, L., Howard, L. W., Thomas, R. M., Moulashis, P., & Santich, S. J. (2021). When it HIITs, you feel no pain: Psychological and psychophysiological effects of respite–active music in high-intensity interval training. *Journal of Sport & Exercise Psychology*, *43*(1), 41–52. https://doi.org/10.1123/jsep.2019-0335

Karageorghis, C. I., Mouzourides, D. A., Priest, D. L., Sasso, T. A., Morrish, D. J., & Walley, C. L. (2009). Psychophysical and ergogenic effects of synchronous music during treadmill walking. *Journal of Sport & Exercise Psychology, 31*(1), 18–36. https://doi.org/10.1123/jsep.31.1.18

Kassavou, A., Turner, A., Hamborg, T., & French, D. P. (2014). Predicting maintenance of attendance at walking groups: Testing constructs from three leading maintenance theories. *Health Psychology*, *33*(7), 752–756. https://doi.org/10.1037/hea0000015

Kellmann, M., & Beckmann, J. (Eds.). (2024). *Fostering recovery and well-being in a healthy lifestyle*. Routledge.

Kim, D., Woo, J., Jeong, J., & Kim, S. (2023). The sound stimulation method and EEG change analysis for development of digital therapeutics that can stimulate the nervous system: Cortical activation and drug substitution potential. *CNS Neuroscience & Therapeutics*, *29*(1), 402–411. https://doi.org/10.1111/cns.14014

Laborde, S., Allen, M. S., Borges, U., Dosseville, F., Hosang, T. J., Iskra, M., Mosley, E., Salvotti, C., Spolverato, L., Zammit, N., & Javelle, F. (2022). Effects of voluntary slow breathing on heart rate and heart rate variability: A systematic review and a meta-analysis. *Neuroscience & Biobehavioral Reviews*, *138*, Article e104711. https://doi.org/10.1016/j.neubiorev.2022.104711

Lakens, D., Scheel, A. M., & Isager, P. M. (2018). Equivalence testing for psychological research: A tutorial. *Advances in Methods and Practices in Psychological Science*, *1*(2), 259–269. https://doi.org/10.1177/2515245918770963

Milton, K., Gomersall, S. R., & Schipperijn, J. (2023). Let's get moving: The Global Status Report on Physical Activity 2022 calls for urgent action. *Journal of Sport and Health Science*, *12*(1), 5–6. https://doi.org/10.1016/j.jshs.2022.12.006

Niven, A., Laird, Y., Saunders, D. H., & Phillips, S. M. (2021). A systematic review and meta-analysis of affective responses to acute high intensity interval exercise compared with continuous moderate- and high-Intensity exercise. *Health Psychology Review*, *15*(4), 540–573. https://doi.org/10.1080/17437199.2020.1728564

Peake, J. M. (2019). Recovery after exercise: what is the current state of play? *Current Opinion in Physiology*, *10*, 17–26. https://doi.org/10.1016/j.cophys.2019.03.007

Razon, S., Hutchinson, J. C., & Tenenbaum, G. (2012). Effort perception. In G. Tenenbaum, R. Eklund, & A. Kamata (Eds.), *Measurement in sport and exercise psychology* (pp. 265–275). Human Kinetics. http://dx.doi.org/10.5040/9781492596332.ch-024

Rejeski, W. J. (1985). Perceived exertion: An active or passive process? *Journal of Sport Psychology*, *7*(4), 371–378. https://doi.org/10.1123/jsp.7.4.371

Rhodes, R. E., Cox, A., & Sayar, R. (2022). What predicts the physical activity intention–behavior gap? A systematic review. *Annals of Behavioral Medicine*, *56*(1), 1–20. https://doi.org/10.1093/abm/kaab044

Rhodes, R. E., & Kates, A. (2015). Can the affective response to exercise predict future motives and physical activity behavior? A systematic review of published evidence. *Annals of Behavioral Medicine*, *49*(5), 715–731. https://doi.org/10.1007/s12160-015-9704-5

Simonsohn, U. (2015). Small telescopes: Detectability and the evaluation of replication results. *Psychological Science*, *26*(5), 559–569. https://doi.org/10.1177/0956797614567341

Stork, M. J., Banfield, L. E., Gibala, M. J., & Martin Ginis, K. A. (2017). A scoping review of the psychological responses to interval exercise: Is interval exercise a viable alternative to traditional exercise? *Health Psychology Review*, *11*, 324–344. https://doi.org/10.1080/17437199.2017.1326011

Stork, M. J., Karageorghis, C. I., & Martin Ginis, K. A. (2019). *Let's Go*! Psychological, psychophysical, and physiological effects of music during sprint interval exercise. *Psychology of Sport and Exercise*, *45*, Article e101547. https://doi.org/10.1016/j.psychsport.2019.101547

Stork, M. J., Kwan, M. Y., Gibala, M. J., & Martin Ginis, K. A. (2015). Music enhances performance and perceived enjoyment of sprint interval exercise. *Medicine & Science in Sports & Exercise*, *47*, 1052–1060. https://doi.org/10.1249/MSS.0000000000000494

Stork, M. J., & Martin Ginis, K. A. (2017). Listening to music during sprint interval exercise: The impact on exercise attitudes and intentions. *Journal of Sports Sciences*, *35*, 1940–1946. https://doi.org/10.1080/02640414.2016.1242764

Tabachnick, B.G., & Fidell, L.S. (2018). *Using multivariate statistics* (7th ed.). Pearson.

Tenenbaum, G. (2001). A social-cognitive perspective of perceived exertion and exertion tolerance. In R. N. Singer, H. A. Hausenblas, & C. Janelle (Eds.), *Handbook of sport psychology* (pp. 810–822). Wiley. https://doi.org/10.1002/9781118270011.ch25

Terry, P. C., Karageorghis, C. I., Curran, M. L., Martin, O. V., & Parsons-Smith, R. L. (2020). Effects of music in exercise and sport: A meta-analytic review. *Psychological Bulletin*, *146*, 91–117. https://doi.org/10.1037/bul0000216

Warburton, D. E. R., Jamnik, V., Bredin, S. S. D., Shephard, R. J., & Gledhill, N. (2019). The 2020 Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and electronic Physical Activity Readiness Medical Examination (ePARmed-X+): 2019 PAR-Q+. *The Health & Fitness Journal of Canada*, *12*(4), 58–61. https://doi.org/10.14288/hfjc.v12i4.295

Table 1

Research Questions, Hypotheses and Associated Analysis Plans

Question	Hypothesis	Analysis Plan
How do in-task music and respite–active music influence affective valence across successive bouts of supramaximal exercise followed by active recovery?	First half: FT–MT, NM–MT > FT–NM, NM–NM (H_{1a}) Second half: FT–MT, NM–MT > FT–NM > NM–NM (H_{1b})	MAN(C)OVA to assess the higher-order, three-way interaction of Condition × Stage × Time Point with primary focus on the two-way interaction of Condition × Time Point, and associated step-down *F* test/Tukey post hoc tests, in order to single out affective valence from affective arousal.
How do in-task music and respite–active music influence affective arousal across successive bouts of supramaximal exercise followed by active recovery?	First half: FT–MT, FT–NM, NM–MT > NM–NM (H_{2a}) Second half: FT–MT, FT–NM > NM–MT > NM–NM (H_{2b})	MAN(C)OVA to assess the higher-order, three-way interaction of Condition × Stage × Time Point with primary focus on the two-way interaction of Condition × Time Point, and associated step-down *F* test/Tukey post hoc tests, in order to single out affective arousal from affective valence.
How do in-task music and respite–active music influence the rating of perceived exertion across successive bouts of supramaximal exercise followed by active recovery?	First half: FT–MT, NM–MT < FT–NM, NM–NM (H_{3a}) Second half: FT–MT < NM–MT < FT–NM, NM–NM (H_{3b})	AN(C)OVA to assess the higher-order, three-way interaction of Condition × Stage × Time Point with primary focus on the two-way interaction of Condition × Time Point, and associated Tukey post hoc tests.
How do in-task music and respite–active music influence state attention across successive bouts of supramaximal exercise followed by active recovery?	First half: FT–MT, NM–MT > FT–NM > NM–NM (H_{4a}) Second half: FT–MT, NM–MT, FT–NM > NM–NM (H_{4b})	AN(C)OVA to assess the higher-order, three-way interaction of Condition × Stage × Time Point with primary focus on the two-way interaction of Condition × Time Point, and associated Tukey post hoc tests.

Continued

Table 1 *Continued*

Question	Hypothesis	Analysis Plan
How do in-task music and respite–active music influence state motivation across successive bouts of supramaximal exercise followed by active recovery?	First half: FT–MT, FT–NM > NM–MT > NM–NM (H_{5a}) Second half: FT–MT > FT–NM > NM–MT > NM–NM (H_{5b})	AN(C)OVA to assess the higher-order, three-way interaction of Condition × Stage × Time Point with primary focus on the two-way interaction of Condition × Time Point, and associated Tukey post hoc tests.
How do in-task music and respite–active music influence remembered pleasure in relation to a HIIT session that has just been completed?	FT–MT > FT–NM, NM–MT > NM–NM (H_6)	One-way, repeated-measures AN(C)OVA with associated pairwise comparisons.
How do in-task music and respite–active music influence exercise enjoyment in relation to a HIIT session that has just been completed?	FT–MT > FT–NM, NM–MT > NM–NM (H_7)	One-way, repeated-measures AN(C)OVA with associated pairwise comparisons.
Are music-liking scores invariant across the fast-tempo and medium-tempo playlists?	Equivalence for fast-tempo playlist vs. medium-tempo playlist (H_8)	TOST to assess equivalence across the two playlists (both *t* tests need to be significant for equivalence to be evidenced).

Note. Wherever a covariate is mentioned, this is $\text{Tolerance}_{\text{diff}}$. *H* = Hypothesis; HIIT = High-intensity interval training (6 × 60-s supramaximal exercise bouts, each followed by 75-s of active recovery); First half = First half of HIIT protocol; Second half = Second half of HIIT protocol; FT–MT = Fast-tempo music (130–135 bpm) during the supramaximal exercise bouts and medium-tempo music (115–120 bpm) during the active-recovery periods; FT–NM = Fast-tempo music during the supramaximal exercise bouts and no music during the active-recovery periods; NM–MT = No music during the supramaximal exercise bouts and medium-tempo music during the active-recovery periods; NM–NM = No music throughout (i.e., control condition); MAN(C)OVA = Multivariate analysis of (co)variance, wherein the covariate will only be used if the associated assumptions are met; AN(C)OVA = Analysis of (co)variance, wherein the covariate will only be used if the associated assumptions are met; TOST = two one-sided *t* tests.

Table 2

Inferential Statistics for Each Dependent Variable

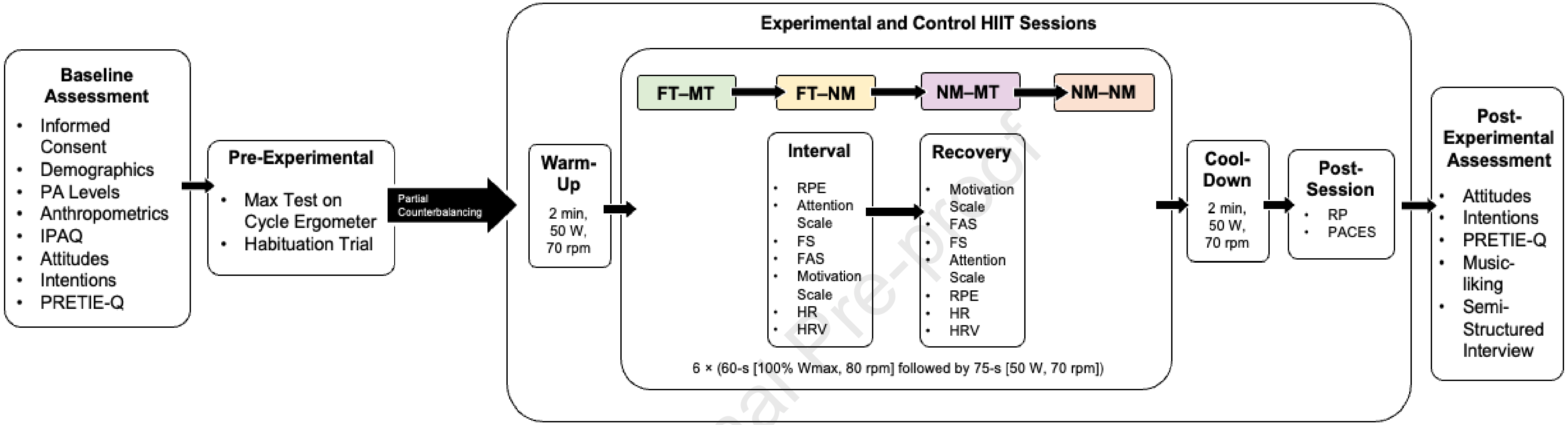
	Pillai's trace	*df*	*F*	*p*	η_p^2
Core affect					
Condition × Stage × Time Point	0.00	6, 862	0.07	.998	–
Condition × Stage	0.00	6, 862	0.10	.996	–
Condition × Time Point	0.00	6, 862	0.18	.982	–
Stage × Time Point	0.00	2, 430	1.42	.243	–
Condition	0.00	6, 862	0.59	.735	–
Stage	0.06	2, 430	14.51	< **.001**	–
Affect	–	1, 26	25.50	< **.001**	.49
Arousal	–	1, 26	23.51	< **.001**	.47
Time Point	0.09	2, 430	22.55	< **.001**	–
Affect	–	1, 26	10.02	**.004**	.28
Arousal	–	1, 26	18.80	< **.001**	.42
RPE					
Condition × Stage × Time Point	–	3, 78	0.39	.757	.01
Condition × Stage	–	3, 78	0.81	.493	.03
Condition × Time Point	–	2.11, 54.76	0.28	.768	.01
Stage × Time Point	–	1, 26	49.21	< **.001**	.65
Condition	–	1.87, 48.58	.70	.492	.03
Stage	–	1, 26	48.21	< **.001**	.65
Time Point	–	1, 26	94.64	< **.001**	.78
State Attention					
Condition × Stage × Time Point	–	2.37, 61.67	1.09	.350	.04
Condition × Stage	–	3, 78	0.63	.595	.02
Condition × Time Point	–	2.26, 58.89	1.86	.159	.07
Stage × Time Point	–	1, 26	8.77	**.006**	.25
Condition	–	1.79, 46.49	0.70	.488	.03
Stage	–	1, 26	20.67	< **.001**	.44
Time Point	–	1, 26	12.01	**.002**	.32
State Motivation					
Condition × Stage × Time Point	–	3, 81	0.68	.568	.02
Condition × Stage	–	3, 81	1.58	.202	.05
Condition × Time Point	–	3, 81	1.09	.358	.04
Stage × Time Point	–	1, 27	5.69	**.024**	.04

	Pillai's trace	*df*	*F*	*p*	η_p^2
Condition	–	3, 81	2.93	**.039**	.10
Stage	–	1, 27	1.54	.226	.05
Time Point	–	1, 27	1.95	.174	.07
Heart Rate					
Condition × Stage × Time Point	–	5.28, 137.30	0.90	.486	.03
Condition × Stage	–	3, 78	0.62	.602	.02
Condition × Time Point	–	2.11, 54,91	0.89	.422	.03
Stage × Time Point	–	2.98, 77.36	4.24	**.008**	.14
Condition	–	2.19, 56.82	2.51	.085	.09
Stage	–	1, 26	17.01	< **.001**	.40
Time Point	–	1.56, 40.63	265.75	< **.001**	.91
Heart Rate Variability					
Condition × Stage × Time Point	.00	30, 2400	0.33	.999	–
Condition × Stage	.00	6, 2400	1.47	.183	–
Condition × Time Point	.01	30, 2400	0.41	.998	–
Stage × Time Point	.03	10, 2400	4.18	< **.001**	–
RMSSD	–	2.16, 54.11	11.62	< **.001**	.32
SDNN	–	2.96, 73.90	2.11	.107	.08
Condition	.02	6, 2400	4.35	< **.001**	–
RMSSD	–	2.14, 53.49	0.50	.620	.02
SDNN	–	3, 75	2.98	**.036**	.11
Stage	.07	2, 1199	47.32	< **.001**	–
RMSSD	–	1, 25	18.74	< **.001**	.43
SDNN	–	1, 25	30.02	< **.001**	.55
Time Point	.22	10, 2400	29.53	< **.001**	–
RMSSD	–	1.53, 38.31	18.69	< **.001**	.43
SDNN	–	1.56, 39.05	68.77	< **.001**	.73
Remembered Pleasure					
Condition	–	2.35, 63.46	1.96	.141	.07
Exercise Enjoyment					
Condition	–	3, 81	1.43	.241	.05

Note. Significant effects are displayed in bold. *df* = degrees of freedom; RPE = rating of perceived exertion; RMSSD = root mean square of the successive RR interval differences; SDNN = standard deviation of normal-to-normal RR intervals.

Figure 1

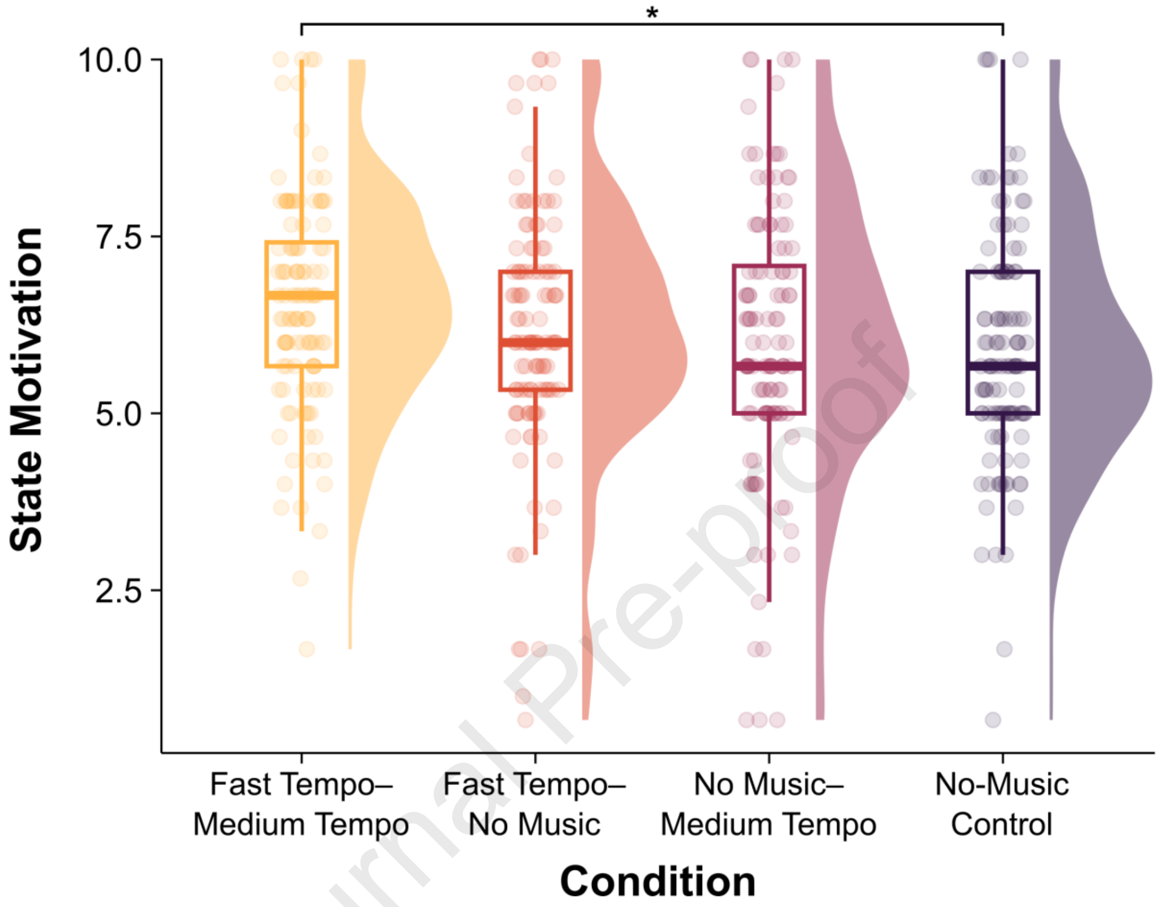
Overview of the Study Protocol



Note. HIIT = high-intensity interval training; PA = physical activity; IPAQ = International Physical Activity Questionnaire; Attitude = attitudes towards HIIT; Intentions = intentions towards HIIT; PRETIE-Q = Preference for and Tolerance of the Intensity of Exercise Questionnaire; W = watts; rpm = revolutions per minute; FT–MT = fast-tempo music (130–135 bpm) during the supramaximal exercise bouts (i.e., interval) and medium-tempo music (115–120 bpm) during the active-recovery periods; FT–NM = fast-tempo music during the supramaximal exercise bouts and no music during the active-recovery periods; NM–MT = no music during the supramaximal exercise bouts and medium-tempo music during the active-recovery periods; NM–NM = no music throughout (i.e., control condition); RPE = rating of perceived exertion; FS = Feeling Scale; FAS = Felt Arousal Scale; HR = heart rate; HRV = heart rate variability; RP = remembered pleasure; PACES = Physical Activity Enjoyment Scale.

Figure 2

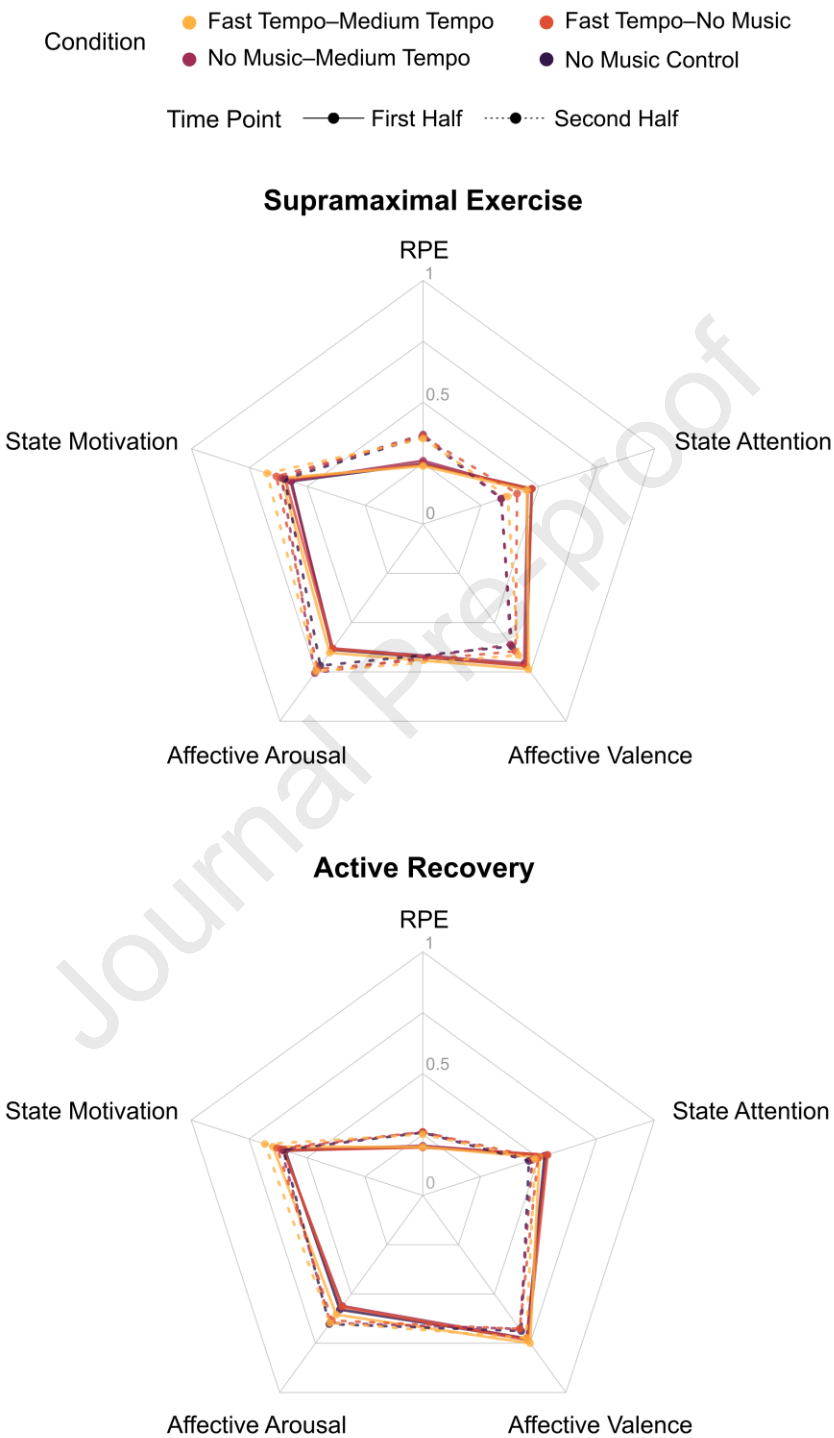
Raincloud Plot for the Significant (p < .05) *Main Effect of Condition on State Motivation*



Note. Box plots and probability density functions are displayed for each condition. Each dot represents an individual participant. *$p < .05$.

Figure 3

Spider Plots Containing All In-Task Measures



Note. Mean scores for each in-task measure. Data for each dependent variables were transformed into a common metric to facilitate visual comparison (i.e., linear transformation to convert estimated marginal means to a 0–1 scale). RPE = rating of perceived exertion.

Highlights

- Examined in-task, asynchronous music and respite–active music in HIIT
- HIIT protocol comprised 6 × 60-s bouts at 100% Wmax with 75-s active recovery
- Music manipulations had little bearing on dependent variables
- State motivation was higher in the fast tempo–medium tempo condition vs. control
- HRV SDNN lower in the fast tempo–no music condition vs. control

Declaration of Competing Interest

None.