# Psychophysiological effects of music on acute recovery from high-intensity interval training

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**Abstract**

Numerous studies have examined the multifarious effects of music applied during exercise but few have assessed the efficacy of music as an aid to recovery. Music might facilitate physiological recovery via the entrainment of respiratory rhythms with music tempo. High-intensity exercise training is not typically associated with positive affective responses, and thus ways of assuaging this warrant further exploration. This study assessed the psychophysiological effects of music on acute recovery and prevalence of entrainment in-between bouts of high-intensity exercise. Thirteen male runners ($M_{age}$ = 20.2 ± 1.9 years; BMI = 21.7 ± 1.7; $\dot{V}O_2$ max = 61.6 ± 6.1 ml·kg·min$^{-1}$) completed three exercise sessions comprising 5 x 5-min bouts of high-intensity intervals interspersed with a 3-min passive recovery period. During recovery, participants were administered positively-valenced music of a slow-tempo (55-65 bpm), fast-tempo (125-135 bpm), or a no-music control. A range of measures including affective responses, RPE, cardiorespiratory indices (gas exchange and pulmonary ventilation), and music tempo-respiratory entrainment were recorded during exercise and recovery. Fast-tempo, positively-valenced music resulted in higher Feeling Scale scores throughout recovery periods ($p < .01$, $\eta_p^2 = .38$). There were significant differences in HR during initial recovery periods ($p < .05$, $\eta_p^2 = .16$), but no other music-moderated differences in cardiorespiratory responses. In conclusion, fast-tempo, positively-valenced music applied during recovery periods engenders a more pleasant experience. However, there is limited evidence that music expedites cardiorespiratory recovery in-between bouts of high-intensity exercise. These findings have implications for athletic training strategies and individuals seeking to make high-intensity exercise sessions more pleasant.

*Keywords:* Affect; Entrainment; Exercise; HIIT; Tempo

## 1. Introduction

A large body of literature has sought to delineate the ergogenic, psychological, and psychophysical effects of music when applied pre-task or as an in-task accompaniment to exercise (e.g., Eliakim et al., 2007; Hutchinson et al., 2011; Karageorghis & Jones, 2014). There is a paucity of literature concerning the application of music as a post-task or recuperative aid, and further exploration is required to elucidate its potential psychological and physiological benefits (Terry & Karageorghis, 2011; Yamasaki et al., 2012). Among the few researchers who have assessed the efficacy of music as a recuperative aid to exercise, Jing and Xudong (2008) explored the effects of sedative music on passive recovery from a 15-min exhaustive cycle ergometer trial. In this instance, sedative music led to decreases in heart rate (HR) intimating the capacity for sedative music to expedite recovery from exercise. Contrastingly, applying motivational music post-exercise encourages participants to engage in a more active recovery which, in turn, leads to reduced blood lactate concentrations (Eliakim et al., 2012).

The emotional quality of music is a salient factor in promoting acute recovery from a stressor and is a noteworthy consideration (see Karageorghis, 2016). Positively-valenced music that induces low-levels of arousal has been shown to promote more effective physiological and subjective recovery from psychological stress (Sandstrom, 2010). The tempo of a piece of music is a determinant of its emotional qualities, with fast-tempo music consistently associated with states characterized by high-arousal and positive affective valence (e.g., Dalla Bella, Peretz, Rousseau, & Gosselin, 2001). Tempo has also been shown to be one of the strongest correlates of physiological responses to music, with fast-tempo music inducing higher breathing and heart rates (Gomez & Danuser, 2007). There is a corpus of literature addressing the capacity of music to regulate emotions and, predominantly, humans respond with positive emotions such as happiness and elation when listening to music (e.g., Juslin, Liljestrom, Vastfjall, Barradas, & Silva, 2008). The findings of Juslin et al. (2008) indicate that humans typically use music to promote positive emotional states, and the propensity for music to elicit such positive states can be harnessed during exercise (Karageorghis, 2017).

**1.1 Exercise Intensity**

Interval exercise has long been a staple of athletic training programs, and high-intensity interval training (HIIT) is becoming increasingly popular among recreationally-active people owing to its cardiovascular and metabolic benefits (e.g., Little et al., 2010). Sedative music might have a role to play in facilitating cardiorespiratory recovery from high-intensity, intermittent exercise via several neurogenic pathways. Animal models suggest that auditory stimulation with classical music directly influences the autonomic nervous system via the gastric vagal nerve, resulting in elevated parasympathetic function (Nakamura et al., 2009). Similarly, humans listening to relaxing music exhibit increased parasympathetic drive, as assessed via heart rate variability (Perez-Lloret et al., 2014). Although not yet studied extensively in exercising individuals, auditory stimuli has been shown to increase parasympathetic drive, leading to reductions in HR, respiration rate, and blood pressure, all of which are key markers of cardiorespiratory recovery. It is possible that musical selections characterized by a slow tempo may elicit similar responses in athletic populations.

In addition to physiological responses to high-intensity exercise, there is evidence to suggest that incremental exercise from low-to-severe intensities causes in-task affective responses to shift from a neutral or positive valence toward a negative valence (e.g., Smith et al., 2015). This shift was conceptualized in the dual-mode model of exercise-related affect (Ekkekakis, 2003) and is a consequence of the continuous interplay between cognitive processes and interoceptive cues (see e.g., Acevedo & Ekkekakis, 2006, pp. 96–104). Although affective valence typically returns to pre-exercise levels following vigorous activity (the so-called “affective rebound”; Ekkekakis, Hall, & Petruzzello, 2008), this phenomenon requires further examination in relation to HIIT, which is characterized by repetitive exercise and multiple rest periods. High-intensity exercise sessions pose a challenge regarding how the decline in affect might be assuaged. Given the increased adoption of HIIT by the general population and that a lack of enjoyment is often cited as a barrier to exercise adherence (Salmon et al., 2003), the affective responses to such exercise are a salient public health issue. There is evidence to support the ergogenic and affect-enhancing benefits of self-selected music across the entire course (during exercise and recovery periods) of a high-intensity interval training session (Stork et al., 2015). Self-selected music, however, is generally unsuitable for studies that seek to examine responses to specific qualities of music (e.g., tempo) owing to the wide variety of music that participants will invariably select (see e.g., Hallett & Lamont, 2016). Moreover, the psycho-acoustic qualities of music tracks vary greatly, which means that a nonstandardized approach poses a threat to the internal validity of studies that examine the mechanisms underlying the efficacy of music.

**1.2 Potential Underlying Mechanisms**

The bio-musicological principle of entrainment pertains to a mechanism that underlies the influence of music on physiological responses. Entrainment theory (Thaut, 2008, pp. 39-59) seeks to explain how music influences the body's main pulses such as brainwaves, HR, and respiratory rate (e.g., Khalfa et al., 2008), and has been attributed, at least in part, to a central "pattern generator" or pacemaker in the brain that serves to regulate temporal functioning (e.g., Schneider et al., 2010). In 12 participants, Haas et al. (1986) observed tight entrainment between music rhythm and respiratory duty cycle (inspiration to expiration time), which was reinforced by rhythmic foot tapping. Furthermore, Bernadi et al. (2005) reported a linear relationship between music tempi (ranging from 55–150 $b \cdot min^{-1}$) and two respiration indices (frequency and minute ventilation). This is of particular relevance to post-exercise recovery given that manipulation of breath movement resulting in an extension of respiratory duty cycle (via deep, slow breathing) has been shown to lower blood pressure and peripheral sympathetic nerve activity (Oneda, Ortega, Gusmao, Arauio, & Mion, 2010). Accordingly, it is plausible that a music-modulated lowering of respiratory rate via the biomusicological principle of entrainment might facilitate cardiorespiratory recovery from strenuous exercise. Of the components that constitute a musical work, it is suggested that tempo is the most salient in promoting entrainment (Khalfa et al., 2008; Thaut, 2008), and further exploration is required to examine the possible role of this constituent of music in promoting post-exercise recovery.

The entrainment research conducted to date has focused predominantly upon resting participants. If such entrainment between bodily rhythms and music can be replicated during the recovery periods of high-intensity exercise, there could be a beneficial influence on the recovery of cardiorespiratory variables by lowering respiratory frequency, and thus HR, to a rate that is determined by the musical beat. This would, in turn, enhance exercise capacity by increasing cardiac reserve for subsequent efforts. Similarly, it may be that starting high-intensity intervals from an enhanced affective state limits the degree of displeasure experienced.

**1.3 Study Aims**

Despite a logical premise and plausible mechanistic foundation, few studies have assessed the influence of music on acute psychological and cardiorespiratory recovery in-between bouts of high-intensity exercise. This study seeks to complement the contemporary theoretical models addressing the use of music in exercise (e.g., Karageorghis, 2016), as well as inform athletic training programs. It was hypothesized that slow-tempo, positively-valenced music applied in-between bouts of high-intensity exercise would promote a more positive psychological state and facilitate acute cardiorespiratory recovery when compared to fast-tempo, positively-valenced music and a no-music control.

## 2. Method

**2.1. Stage 1: Music Selection**

Twenty four music tracks were initially selected by the experimenters based on the tempo ranges required to address the research question (12 slow-tempo: 55-65 bpm; 12 fast-tempo: 125-135 bpm). Tracks included in this selection had readily discernible beats that matched the published tempo. Owing to difficulty in identifying suitable tracks in the range of 55-65 bpm, those at a tempo of ± 3 bpm were considered and digitally altered if appropriate. Previous empirical work indicates that tempo changes of ± 4 bpm are indiscernible among nonmusicians (Levitin & Cook, 1996).

Eight participants ($M_{age}$ = 25.2 ± 3.6 years) rated the 24 music tracks (3 min excerpts) with the aim of identifying those suitable for use in the experimental protocol (Stage 2). Participants at each stage of the study were similar in terms of age (18–30 years), and socio-cultural background (had spent their formative years in the UK). Participants who reported any form of hearing deficiency or congenital amusia (i.e., tone-deafness) were excluded. The 24 musical excerpts were rated using the Affect Grid (Russell et al., 1989), providing two scores in line with each of its two dimensions: pleasure–displeasure and low arousal–high arousal. Five slow-tempo tracks that were rated in the bottom-right quadrant of the Affect Grid (i.e., “pleasant low-arousal”), and within one whole unit of each other in terms of affective valence and arousal scores, were selected for use in the experimental trials (see Table 1). Five fast-tempo tracks that were rated in the upper-right quadrant of the Affect

Grid (i.e., “pleasant high-arousal”) and within one whole unit of each other were selected for use in Stage 2 (see Table 1). The affective valence (pleasure–displeasure) ratings of the slow- and fast-tempo tracks were within one whole unit of each other, and the arousal scores for the fast-tempo tracks were ~4 units higher than those for the slow-tempo tracks.

## 2.2. Stage 2: Experimental Investigation

**2.2.1. Power analysis.** To establish appropriate sample size, a power analysis was undertaken using the software G*Power3 (Faul et al., 2007). Based on a more conservative effect size than that of Stork et al. (2015; $\eta_p^2 = .06$), an alpha level of .05, and power at .8 to protect beta at four times the level of alpha (Cohen, 1988, pp. 4–6), the analysis indicated that 12 participants would be required to detect effects on affective responses (Feeling Scale).

**2.2.2. Participants.** Twenty well-trained, male middle-distance runners were initially recruited for the experimental investigation, however, seven of these failed to complete all sessions owing to injury, competitive commitments, or inability to sustain the required work rate. Therefore, 13 participants completed all experimental conditions ($M_{age}$ = 20.2 ± 1.9 years; BMI = 21.7 ± 1.7). Experimental procedures were approved by the ____ Research Ethics Committee and participants provided written informed consent. Participants were asked to abstain from exercise for 24 h, alcohol and caffeine for 12 h, and food for 3 h prior to each visit. Participants were similar in terms of training status and maximal aerobic capacity (see Table 2).

**2.2.3. Apparatus and measures.** Participants exercised on a treadmill (HP Cosmos Saturn) while cardiorespiratory data were collected on a breath-by-breath basis using an online gas analyzer (Oxycon Pro), and HR monitored via telemetry (Vantage NV). Music was played from a laptop computer connected to over-ear headphones (Sennheiser HD201) at a standardized sound intensity (75 dBA). Pre- and post-exercise blood samples were collected into a 10 µl capillary tube and subsequently analyzed for blood lactate concentration (Biosen). Rating of perceived exertion (RPE) was recorded using the Borg CR10 scale (Borg, 1998). Affective valence and arousal were assessed using the Feeling Scale (FS; Hardy & Rejeski, 1989) and the Felt Arousal Scale (FAS; Svebak & Murgatroyd, 1985), respectively. Van Landuyt et al. (2000) found the FS to be correlated (0.51–0.88) with the valence scale of the Self-Assessment Manikin and with the Affect Grid (0.41–0.59).

Ekkekakis (2013) suggested that the tandem use of the FS and FAS strengthened the discriminant validity of the scales.

**2.2.4. Tempo-respiratory entrainment.** Music tempo and respiratory rhythms were considered to be matched when the instantaneous ratio of tempo to mean respiratory frequency, recorded at 15 s intervals, was within ± 0.05 of a whole- or half-integer value (see Paterson et al., 1986). The prevalence of tempo-respiratory entrainment (ENT%) was calculated as the percentage of the sampled data within each 3-min recovery period that met these criteria. The first and last 15 s of each 3-min block were excluded from the analysis to account for the stabilization of respiratory pattern and the recording of perceptual responses, respectively.

**2.2.5. Maximal exercise test and habituation.** Participants completed a maximal ramp incremental exercise test on a motorized treadmill. Exercise commenced at 10 $km \cdot hr^{-1}$ for 4 min at a 1% incline (warm-up) after which the speed was increased by 1 $km \cdot hr^{-1}$ each minute until volitional fatigue was reached. The test was designed to elicit maximal capacities within 8–12 min. Gas exchange and HR were assessed continuously. Maximal aerobic capacity was deemed to have been reached following the attainment of a single primary (plateau in oxygen uptake following an increase in exercise intensity) or two secondary criteria (final RER ≥ 1.15, and HR within 10 bpm of age-predicted maximum) in accord with BASES Guidelines (Winter et al., 2006). Following the test, gas exchange threshold (GET) was identified using multiple parallel methods (Wasserman, 1984). Subsequent to the maximal exercise test, participants were familiarized with the experimental protocol and measures.

**2.2.6. Experimental protocol.** Participants completed three exercise sessions separated by a minimum of 2 days and a maximum of 7 days. Each session comprised a 4-min period of seated rest, followed by a 4-min warm-up at a treadmill speed equivalent to 80% GET. Participants then completed 5 x 5-min bouts of treadmill running at a speed equivalent to 20% of the difference between GET and $\dot{V}O_2$ max ("heavy" exercise; Lansley et al., 2011), interspersed with 3-min periods of standing recovery on the treadmill. A passive, standing recovery was selected to remove the potential influence of locomotor–respiratory coupling that could manifest during an active (walking) recovery period (Daley et al., 2013); such coupling might have confounded the assessment of tempo–respiratory entrainment. During the standing recovery periods of a given session, participants were administered one of the following conditions: slow-tempo music; fast-tempo music; or no-music (control). To ensure parity of experience across conditions, headphones were worn during the control condition. The order of conditions was randomized and exercise bouts were completed individually at the same time of day to account for circadian variance.

The FS (Hardy & Rejeski, 1989) and FAS (Svebak & Murgatroyd, 1985) were administered immediately prior to the warm-up. Rating of perceived exertion (Borg, 1998) was assessed in the final 10 s of each exercise bout. At the end of each bout, the participant straddled the treadmill belt and headphones were placed over his ears. The music tracks had a 1-s fade-in and fade-out to avoid the startle effect (Sandstrom, 2010). Gas exchange and ventilatory function were recorded continuously throughout the aforementioned procedures; HR was recorded at the end of each bout and at the end of each recovery period. The FS and FAS were administered 10 s before the end of the 3-min recovery period. Thereafter, the participant resumed treadmill running. Blood lactate concentration was sampled at resting baseline and immediately following the final music intervention using a 10 µl earlobe capillary sample (Biosen).

**2.3. Data Analysis**

Following checks to ensure that the data were suitable for parametric analysis, a series of MANOVAs and ANOVAs were applied. A 3 (condition) x 6 (time) MANOVA was used to analyze responses to the Feeling Scale and Felt Arousal Scale; this analysis incorporated the baseline responses. A series of 3 (condition) x 5 (time) ANOVAs were computed for the following dependent variables: RPE, lowest HR during recovery period, mean breathing frequency during recovery ($f_R$), $O_2$ uptake during recovery ($\dot{V}O_2$), minute ventilation ($\dot{V}_E$) and mean Tidal Volume ($V_T$) throughout the recovery periods, and respiratory duty cycle ($T_{TOT}$) during recovery. A series of 3 (condition) x 4 (time) ANOVAs was applied to HR (peak) and respiration measures collected during exercise ($\dot{V}O_2$, $\dot{V}_E$, $V_T$, and $T_{TOT}$). The four exercise periods following the initial recovery period were included in these analyses to explore the effects of the intervention, which only become relevant from the second exercise bout. A 3 (condition) x 2 (time) ANOVA was applied for pre- and post-exercise blood lactate values. The amount of time respiration rate was entrained with music tempo was analyzed using a 2 (condition) x 5 (time) ANOVA.

## 3. Results

Data screening revealed no univariate ($z < \pm3.29$) or multivariate outliers ($p < .001$). Tests of the distributional properties of the data in each cell of the analysis revealed 59 violations ($z > \pm1.96$). Specifically, the data for HR at the end of the recovery period and $T_{TOT}$ during exercise and recovery exhibited positive skewness; therefore, a logarithmic transformation (log10) was applied to normalize these data. Mauchly's test indicated 21 instances in which the sphericity assumption had been violated; therefore appropriate adjustments were applied to the relevant *F* tests. Descriptive statistics for exercise bouts are presented in Table 3 and for recovery periods in Table 4.

### 3.1. Affective Responses

RM MANOVA for affective responses (Feeling Scale and Felt Arousal Scale; Table 4) indicated no interaction effects (Pillai's Trace = .167, $F[20, 240] = 1.10$, $p = .357$, $\eta_p^2 = .08$). However, there was a significant effect of condition (Pillai's Trace = .425, $F[4, 48] = 3.24$, $p = .020$, $\eta_p^2 = .21$) and time (Pillai's Trace = .438, $F[10, 120] = 3.36$, $p = .001$, $\eta_p^2 = .22$). Step-down *F* tests are presented for each measure.

**3.1.1. Feeling Scale (FS).** The main effect of condition was significant, $F(1.37, 16.39) = 7.38$, $p = .010$, $\eta_p^2 = .38$ with follow-up pairwise comparisons indicated that the fast-tempo music condition was rated as significantly more pleasant than the no-music control (95% CI [1.31, .44], $p = .000$; see Figure 1 and Table 4). The main effect of time was nonsignificant, $F(2.01, 24.12) = .22$, $p = .803$, $\eta_p^2 = .02$.

**3.1.2. Felt Arousal Scale (FAS).** There was no main effect of condition, $F(2, 24) = 1.16$, $p = .330$, $\eta_p^2 = .09$. The main effect of time was significant, $F(2.20, 26.41) = 5.87$, $p = .006$, $\eta_p^2 = .33$, with follow-up pairwise comparisons indicating that all recovery bouts resulted in higher levels of arousal compared to baseline.

### 3.2. Psychophysical Response

**3.2.1. Rating of Perceived Exertion (RPE).** There was no condition x time interaction, $F(8, 96) = 1.72$, $p = .103$, $\eta_p^2 = .13$, and the main effect of condition was also nonsignificant, $F(2, 24) = .67$, *p* = .523, $\eta_p^2$ = .05. There was a main effect of time, *F*(1.28, 15.40) = 13.79, *p* = .001, $\eta_p^2$ = .54, with follow-up pairwise comparisons indicating that levels of exertion were elevated in the final three exercise bouts when compared to the initial two exercise bouts (*p* < .05; Table 3).

### 3.3. Cardiorespiratory Responses

A series of significant main effects of time were revealed in analyses of HR, $\dot{V}_E$, $V_T$, $f_R$, and $T_{TOT}$ during exercise bouts and recovery periods with data indicating increased stress as the exercise session progressed (*p* < .01).

**3.3.1. Heart rate during exercise.** Analysis revealed no condition x time interaction, *F*(8, 88) = .32, *p* = .958, $\eta_p^2$ = .03, and no main effect of condition, *F*(2, 22) = .03, *p* = .972, $\eta_p^2$ = .01 (Table 3).

**3.3.2. Heart rate during recovery.** Analysis indicated a significant condition x time interaction, *F*(8, 96) = 2.12, *p* = .034, $\eta_p^2$ = .16, which was associated with a large effect. Inspection of the means and standard errors indicated that HR was lower during the control condition in Recovery Period 1 when compared to both music conditions, and that HR was lower during the slow-tempo music condition during Recovery Period 2 when compared to fast-tempo music. Finally, HR was lower during the fast-tempo music condition in Recovery Period 4 when compared to control (see Figure 2 and Table 4). The main effect of condition was nonsignificant, *F*(2, 24) = .06, *p* = .945, $\eta_p^2$ = .01.

**3.3.4. Oxygen uptake (% of $\dot{V}O_2$ max).** Oxygen uptake was recorded continuously throughout all exercise and recovery periods and was analyzed as a percentage of maximal aerobic capacity. The condition x time interaction during exercise was nonsignificant, *F*(2.67, 32.02) = .29, *p* = .812, $\eta_p^2$ = .02. There were no main effects of condition, *F*(1.26, 15.14) = 1.09, *p* = .330, $\eta_p^2$ = .08, or time, *F*(3, 36) = .39, *p* = .449, $\eta_p^2$ = .03. Similarly, there was no condition x time interaction for the recovery periods, *F*(8, 96) = .60, *p* = .776, $\eta_p^2$ = .05, and no main effect of condition, *F*(1.28, 15.38) = 1.39, *p* = .267, $\eta_p^2$ = .10, or time, *F*(4, 48) = 1.69, *p* = .168, $\eta_p^2$ = .12.

**3.3.5. Minute ventilation ($\dot{V}_E$).** There was no condition x time interaction during the exercise bouts, *F*(3.04, 36.51) = .75, *p* = .608, $\eta_p^2$ = .06, or a main effect of condition, *F*(2, 24) = .00, *p* = .997, $\eta_p^2$ = .00. During recovery periods, there was no significant condition x time interaction, *F*(8, 96) = .90, *p* = .523, $\eta_p^2$ = .07, or main effect of condition, *F*(2, 24) = 1.18, *p* = .324, $\eta_p^2$ = .09.

**3.3.6. Tidal volume ($V_T$).** For measures taken during exercise, there was a nonsignificant condition x time interaction, $F(1.59, 19.10) = 1.70$, $p = .211$, $\eta_p^2 = .12$, and a nonsignificant main effect of condition, $F(2, 24) = .56$, $p = .583$, $\eta_p^2 = .04$. There was no condition x time interaction, $F(8, 96) = .83$, $p = .583$, $\eta_p^2 = .06$, or main effect of condition, $F(2, 24) = 2.08$, $p = .147$, $\eta_p^2 = .15$, for recovery period data.

**3.3.7. Respiratory frequency ($f_R$).** Data collected during exercise indicated no condition x time interaction, $F(1.86, 22.37) = 1.25$, $p = .302$, $\eta_p^2 = .10$, and similarly, a nonsignificant main effect of condition, $F(2, 24) = .28$, $p = .756$, $\eta_p^2 = .02$. During recovery periods, there was no significant condition x time interaction, $F(3.53, 42.30) = .28$, $p = .870$, $\eta_p^2 = .02$, or main effect of condition, $F(2, 24) = .42$, $p = .663$, $\eta_p^2 = .03$.

**3.3.8. Respiratory duty cycle ($T_{TOT}$).** There was no significant condition x time interaction during exercise bouts, $F(1.51, 18.14) = .81$, $p = .569$, $\eta_p^2 = .06$. There was also no main effect of condition, $F(1.36, 16.65) = 1.36$, $p = .273$, $\eta_p^2 = .10$. During the recovery periods, there was no significant condition x time interaction, $F(8, 96) = .18$, $p = .994$, $\eta_p^2 = .01$, or main effect of condition, $F(2, 24) = 1.77$, $p = .193$, $\eta_p^2 = .13$.

### 3.4. Blood Lactate

There was no significant condition x time interaction, $F(2, 24) = 1.12$, $p = .342$, $\eta_p^2 = .09$, and no main effect of condition, $F(2, 24) = .70$, $p = .509$, $\eta_p^2 = .05$. There was a significant main effect of time, $F(1, 12) = 28.22$, $p = .000$, $\eta_p^2 = .70$, indicating that post-exercise values were higher ($M = 4.40 \pm .61$) than baseline ($M = 1.05 \pm .09$).

### 3.5. Tempo-Respiratory Entrainment

The condition x time interaction effect was nonsignificant ($F[4, 48] = .58$, $p = .676$, $\eta_p^2 = .05$), as were the main effects of condition and time ($p > .05$).

## 4. Discussion

The purpose of this study was to assess the influence of music on acute psychological and cardiorespiratory recovery in between bouts of high-intensity exercise among trained participants. Our research hypothesis was not supported given that fast-tempo music, rather than slow-tempo music, positively influenced affective responses in all recovery periods when compared to a no-music control condition. Furthermore, music does not appear to facilitate acute cardiorespiratory recovery in between bouts of high-intensity treadmill exercise.

**4.1. Affective Responses**

Listening to fast-tempo, positively-valenced music (125-135 bpm) during the 3-min recovery periods engendered a more pleasant experience when compared to a no-music control eliciting a FS score of ~1 higher ($p$ = .010; $\eta_p^2$ = .38). This was a consistent finding across each of the five recovery periods (see Figure 1), and was associated with a large effect size indicating a robust result. The positive affective response to music is concordant with other exercise-related studies (e.g., Stork et al., 2015) and the efficacy of fast-tempo music in this instance could be associated with the HR range recorded in the present study. A corpus of work has explored the relationship between exercise HR and preference for music tempo (see Karageorghis & Jones, 2014). This work shows that, regardless of exercise intensity (40–90% maxHRR), there is a preference for fast-tempo music during treadmill exercise and cycle ergometry. These studies explored the application of in-task music (during exercise) with working heart rates ranging from ~110 to ~180 $b \cdot min^{-1}$ and participants in the present study exhibited heart rates ranging from ~105 to ~180 $b \cdot min^{-1}$ during recovery periods. It appears that fast-tempo music elicits the most positive affective responses when heart rates are elevated, whether this is during exercise or recovery periods.

The arousal reported by participants during the recovery periods increased significantly from baseline ($p$ = .006; FAS = 3.08 ± 0.17), but remained stable throughout recovery periods (FAS = 3.77 ± 0.17 [Recovery Period 1]; 3.82 ± 0.23 [Recovery Period 2]; 3.87 ± 0.27 [Recovery Period 3]; 3.87 ± 0.29 [Recovery Period 4]; 3.56 ± 0.23 [Recovery Period 5]). Although the fast-tempo music selections were rated as more highly-arousing than the slow-tempo tracks during the music selection process (Stage 1), this was not reflected during the recovery periods. It appears that arousal increased independently of the music administered and that the exercise was sufficient to significantly increase arousal from baseline. The elevated arousal resulting from the intervals may have been sufficient for participants to maintain an optimal arousal level for the session without any need for music to help in regulating arousal.

**4.2. Cardiorespiratory Responses**

The significant interaction effect of condition x time for the HR recovery ($p$ = .034, $\eta_p^2$ = .16) indicated that participants exhibited a lower HR at the end of the first recovery period during control, and a lower HR during the second recovery period in the slow-tempo condition when compared to the fast-tempo condition. Given that participants were engaged in prolonged exercise above the GET, there was substantial cardiorespiratory drift, during which oxygen uptake and ventilation increased progressively, as illustrated by the multiple main effects of time. Therefore, any music-moderated effect on recovery HR would likely manifest in the early recovery periods. Despite the HR interactions observed during recovery, there was no subsequent influence on exercise HR or associated cardiorespiratory variables (see Table 3). This suggests that, in this population, lower HR during early recovery periods is of limited physiological benefit in subsequent bouts of exercise.

**4.3. Tempo-Respiratory Entrainment**

Previous studies reported entrainment of breathing and music rhythms at rest (e.g., Haas et al., 1986; Bernadi et al., 2005), but the present study did not replicate these findings in an exercise context. Despite Khalfa et al.'s (2008) suggestion that entrainment is a partially conscious process, exercise ventilation is controlled by neural and humeral factors to enable the delivery of oxygen and elimination of carbon dioxide (Forster et al., 2012). Consequently, it appears that when ventilation is high, maintenance of homeostatic equilibrium will be the predominating factor in the control of ventilation. During the first recovery period when ventilation was lowest, values were in excess of three times those at rest (36.8 ± 10.7 vs. 11.2 ± 2.9 $L\cdot min^{-1}$) and it seems as though such a high demand restricts the likelihood of entrainment being manifest. The present results suggest that only resting respiration would be susceptible to the subtle influence of music tempo on respiratory function.

The conscious and unconscious aspects of different types of entrainment may be a salient factor (Phillips-Silver et al., 2010). Entrainment between musical tempo and HR is an unconscious process, but entrainment between respiration rate and music tempo can be either conscious or unconscious given that humans breathe without conscious cognitive control, but can also choose to regulate breathing rate. From an information processing perspective, the notion of a limited attentional capacity may be relevant when considering the capacity to process, and entrain with, external stimuli such as music during periods of physical stress. Rejeski's (1985) model of parallel processing indicates that informational and emotional components are processed in parallel, rather than in sequence. Furthermore, as exercise intensity increases, informational cues become stronger and occupy the limited capacity of channels between preconscious and focal awareness. It might be that during recovery from high-intensity exercise, internal informational cues predominate and there is insufficient capacity remaining to process musical stimuli in order to consciously manipulate respiration rate.

**4.4 Technical Considerations**

A high number of participants (*n* = 7) were unable to complete all of the testing sessions. We applied an exercise intensity of $\Delta 20\text{-}\dot{V}O_2$ max, which is considered to be "heavy" exercise (Lansley et al., 2011). This typifies an intensity at which athletes train for periods of ~3 min. The 5-min bout was selected to allow for a relative steady-state in physiological responses, and the 3-min recovery period to enable sufficient exposure to the musical stimuli (i.e., the musical stimuli would have long enough to take effect). However, two participants were unable to tolerate the physical stress associated with the extended interval duration. Future studies might seek to explore the role of music in promoting recovery during alternative protocols such as the so-called *practical model* of low volume, high intensity interval training (Little, Safdar, Wilkin, Tarnopolsky, & Gibala, 2010). The remaining five participants withdrew owing to injury (*n* = 3) or competitive commitments (*n* = 2).

**4.5. Practical Implications**

The hypothesis that slow-tempo, positively-valenced music would promote the most positive psychological state during recovery was based on previous suggestions (Terry & Karageorghis, 2011), and findings that sedative music promotes effective psychological and physiological exercise recovery (Jing & Xudong, 2008). There are some notable differences between previous work and the present study that may explain the nature of our results. First, previous work has framed post-task, or recuperative, music in the context of the final phase of an exercise session (i.e., no further bouts of exercise within the session) but the present study sought to explore the utility of music as an aid to recovery that took place *in between* repeated bouts of exercise. This is likely a seminal difference and would suggest the need for terminological distinction. Accordingly, it is proposed that the term *respite music* is adopted by researchers and practitioners to more accurately describe the application of music during periods of recovery within an exercise session. The proposed term provides a useful counterpoint to *recuperative music*, which refers to sedative music that is applied immediately after an exercise or training session (Terry & Karageorghis, 2011).

The capacity for music to positively enhance the exercise experience has been demonstrated in a number of studies (e.g., Hutchinson et al., 2011; Karageorghis & Jones, 2014). The present study extends that work to suggest that fast-tempo, positively-valenced music can be used to afford an effective respite that positively enhances the pleasure experienced during a high-intensity interval session. The concept of “affective rebound” (Ekkekakis et al., 2008) demonstrates that affective valence returns to pre-exercise levels almost immediately following cessation of exercise. Present data indicate that pleasure can be enhanced beyond pre-exercise levels through the administration of fast-tempo, positively-valenced music during the rest periods of an interval running session in trained participants. Furthermore, there are numerous studies reporting a link between acute affective responses to exercise and subsequent adherence to exercise (see Rhodes & Kates, 2015 for a review); interventions that can enhance acute affective responses in untrained populations warrant additional investigation.

Given the typical affective responses during exercise, as depicted in the dual-mode model (Ekkekakis, 2003), the high-intensity exercise bout itself will not typically result in positive affective responses but the rest periods in-between exercise bouts offer an opportunity to ameliorate this displeasure. Therefore, the use of fast-tempo, positively-valenced music appears to promote a more pleasurable and thus *tolerable* exercise experience.

## 5. Conclusion

The present findings indicate that fast-tempo, positively-valenced music engenders positive affective responses in the acute recovery phases of high-intensity interval training performed by middle-distance runners. This finding is of relevance to coaches and practitioners working with athletes and recreational exercisers, as it offers an easily implementable intervention by which to increase the pleasure experienced during a physically demanding session. The findings are in accord with other work indicating that music can enhance affective responses in a high-intensity exercise context (e.g., Stork & Martin Ginis, 2016). The recorded physiological responses do not provide robust evidence that slow or fast-tempo music expedites recovery in this context. Future research might seek to examine the effects of music during the recovery periods following exercise performed at lower intensities; specifically focusing on the extent to which music promotes respiratory entrainment. A terminological distinction has been proposed herein to differentiate *recuperative* music (applied post-task) from *respite* music (applied in-between bouts of exercise). Respite music has pleasant–arousing qualities, in line with the activated state of the organism during a brief recovery period, whereas recuperative music that is employed on cessation of exercise is characterized by pleasant–relaxing qualities.

## 6. References

Acevedo, E., & Ekkekakis, P. (2006). *Psychobiology of physical activity*. Champaign, IL: Human Kinetics.

Bernardi, L. (2005). Cardiovascular, cerebrovascular, and respiratory changes induced by different types of music in musicians and non-musicians: the importance of silence. *Heart*, *92,* 445–452. http://dx.doi.org/10.1136/hrt.2005.064600

Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinetics.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Daley, M. A., Bramble, D. M., & Carrier, D. R. (2013). Impact loading and locomotor-respiratory coordination significantly influence breathing dynamics in running humans. *PLOS ONE*, *8*, e70752.

Dalla Bella, S., Peretz, I., Rousseau, L., & Gosselin, N. (2001). A developmental study of the affective value of tempo and mode in music. *Cognition, 80,* B1–B10.

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

Ekkekakis, P. (2013). *The measurement of affect, mood, and emotion*. New York, NY: Cambridge University Press.

Ekkekakis, P., Hall, E. E., & Petruzzello, S. J. (2008). The relationship between exercise intensity and affective responses demystified: To crack the 40-year-old nut, replace the 40-year-old nutcracker! *Annals of Behavioral Medicine, 35,* 136–149. doi:10.1007/s12160-008-9025-z

Eliakim, M., Meckel, Y., Nemet, D., & Eliakim, A. (2007). The effects of music during warm-up on consecutive anaerobic performance in elite adolescent volleyball players. *International Journal of Sports Medicine, 28,* 321–325. doi:10.1055/s-2006-924360

Eliakim, M., Bodner, E., Eliakim, A., Nemet, D., & Meckel, Y. (2012). Effect of motivational music on lactate levels during recovery from intense exercise. *The Journal of Strength and Conditioning Research, 26,* 80–86. doi:10.1519/JSC.0b013e31821d5f31

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39,* 175–191.

Forster, H. V., Haouzi, P., & Dempsey, J. A. (2012). Control of breathing during exercise. *Comprehensive Physiology, 2,* 743–777.

Gomez, P., & Danuser, B. (2007). Relationships between musical structure and psychophysiological measures of emotion. *Emotion, 7,* 377–387.

Haas, F., Distenfeld, S., & Axen, K. (1986). Effects of perceived musical rhythm on respiratory pattern. *Journal of Applied Physiology, 61,* 1185–1191.

Hallett, R. J. & Lamont, A. M. (2016). Evaluation of a motivational pre-exercise music intervention. *Journal of Health Psychology*. Advance online publication. doi:10.1177/1359105316674267

Hardy, C. J., & Rejeski, W. J. (1989). Not what but how one feels: The measurement of affect during exercise. *Journal of Sport & Exercise Psychology, 11,* 304–317.

Hutchinson, J. C., Sherman, T., Davis, L. K., 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,* 135–142.

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,* 102–106.

Juslin, P. N., Liljestrom, S., Vastfjall, D., Barradas, G., & Silva, A. (2008). An experience sampling study of emotional reactions to music: Listener, music, and situation. *Emotion*, *8*, 668–683. doi:10.1037/a0013505.

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). London, UK: Routledge.

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

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,* 299–310. doi:10.1016/j.psychsport.2013.08.004

Khalfa, S., Roy, M., Rainville, P., Dalla Bella, S., & Peretz, I. (2008). Role of tempo entrainment in psychophysiological differentiation of happy and sad music? *International Journal of Psychophysiology, 68,* 17–26. doi:10.1016/j.ijpsycho.2007.12.001

Lansley, K., DiMenna, F., Bailey, S., & Jones, A. (2011). A “New” method to normalise exercise intensity. *International Journal of Sports Medicine, 32*, 535–541. doi: 10.1055/s-0031-1273754

Levitin, D. J., & Cook, P. R. (1996). Memory for musical tempo: Additional evidence that auditory memory is absolute. *Perception and Psychophysics, 58,* 927–935.

Little, J. P., Safdar, A., Wilkin, G. P., Tarnopolsky, M. A., & Gibala, M. J. (2010). A practical model of low-volume high-intensity interval training induces mitochondrial biogenesis in human skeletal muscle: potential mechanisms. *The Journal of Physiology, 588,* 1011–1022. doi:10.1113/jphysiol.2009.181743

Nakamura, T., Mamoru, T., Akira, N., & Katsuya, N. (2009). Effect of auditory stimulation on parasympathetic nerve activity in urethane-anesthetized rats. *International Journal of Experimental and Clinical Pathophysiology and Drug Research*, *23*, 415-419.

Oneda, B., Ortega, K.C., Gusmão. G.L., Araújo, T.G. & Mion, D. Jr. (2010). Sympathetic nerve activity is decreased during device-guided slow breathing. *Hypertension Research, 33*, 708-12.

Paterson, D., Wood, G., Morton, A., & Henstridge, J. (1986). The entrainment of ventilation frequency to exercise rhythm. *European Journal of Applied Physiology and Occupational Physiology, 55*, 530–537. doi: 10.1007/BF00421649

Perez-Lloret, S., Braidot, N., Cardinali, D., Delvenne, A., Diez, J., Dome, M., & Vigo, D. (2014). Effects of different “relaxing” music styles on the autonomic nervous system. *Noise Health, 16*, 279–284. http://dx.doi.org/10.4103/1463-1741.140507

Phillips-Silver, J., Aktipis, C. A., & Bryant, G. A. (2010). The ecology of entrainment: Foundations of coordinated rhythmic movement. *Music Perception: An Interdisciplinary Journal*, *28,* 3–14.

Rejeski, W. J. (1985). Perceived exertion: An active or passive process? *Journal of Sport Psychology, 75,* 371–378.

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,* 715–731.

Russell, J. A., Weiss, A., & Mendelsohn, G. A. (1989). Affect grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology, 57,* 493–502. doi:10.1037/0022-3514.57.3.493

Salmon, J., Owen, N., Crawford, D., Bauman, A., & Sallis, J. F. (2003). Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. *Health Psychology, 22,* 178.

Sandstrom, G. M., & Russo, F. A. (2010). Music hath charms: The effects of valence and arousal on recovery following an acute stressor. *Music and Medicine, 2,* 137–143.

Schneider, S., Askew, C. D., Abel, T., & Strūder, H. K. (2010). Exercise, music, and the brain: Is there a central pattern generator? *Journal of Sports Sciences, 28,* 1337–1343. doi:10.1080/02640414.2010.507252

Smith, A. E., Eston, R., Tempest, G. D., Norton, B., & Parfitt, G. (2015). Patterning of physiological and affective responses in older active adults during a maximal graded exercise test and self-selected exercise. *European Journal of Applied Physiology*, *115*, 1855–1866.

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

Stork, M. J., & Martin Ginis, K. A. (2016). Listening to music during sprint interval exercise: The impact on exercise attitudes and intentions. *Journal of Sports Sciences*, 1-7. Advance online publication. doi: http://dx.doi.org/10.1080/02640414.2016.1242764

Svebak, S., & Murgatroyd, S. (1985). Metamotivational dominance: A multimethod validation of reversal theory constructs. *Journal of Personality and Social Psychology, 48,* 107–116. doi:10.1037/0022-3514.48.1.107

Terry, P. C., & Karageorghis, C. I. (2011). Music in sport and exercise. In T. Morris & P. C. Terry (Eds.), *The new sport and exercise psychology companion* (pp. 359–380). Morgantown, WV: Fitness Information Technology.

Thaut, M. H. (2008). *Rhythm, music and the brain: Scientific foundations and clinical applications.* New York, NY: Routledge.

Van Landuyt, L. M., Ekkekakis. P., Hall, E. E., & Petruzzello, S. J. (2000). Throwing the mountains into the lakes: On the perils of nomothetic conceptions of the exercise-affect relationship. *Journal of Sport & Exercise Psychology, 22,* 208–234.

Wasserman, K. (1984). The anaerobic threshold measurement to evaluate exercise performance. *American Review of Respiratory Disease, 129,* S35-S40. http://dx.doi.org/10.1164/arrd.1984.129.2p2.s35

Winter, E., Jones, A., Davison, R., Bromley, P., & Mercer, T. (2006). *Sport and Exercise Physiology Testing Guidelines*. Hoboken, NJ: Taylor & Francis.

Yamasaki, A., Booker, A., Kapur, V., Tilt, A., Niess, H., Lillemoe, K. D., ... & Conrad, C. (2012). The impact of music on metabolism. *Nutrition, 28,* 1075–1080.

Table 1

*Music Tracks Administered in the Experimental Conditions*

| Track Title | Artist(s) | Year of release | Official bpm | Affect Rating (*M*) | Arousal Rating (*M*) |
|---|---|---|---|---|---|
| Slow tempo | | | | | |
| At The River | Groove Armada | 1998 | 68 | 6.83 ± 1.47 | 2.83 ± 0.41 |
| Can You Feel The Love Tonight | Elton John | 1994 | 67 | 6.33 ± 1.21 | 3.00 ± 1.10 |
| I Wanna Be Yours | Arctic Monkeys | 2013 | 67 | 6.17 ± 1.94 | 3.50 ± 0.55 |
| At Last | Etta James | 1960 | 56 | 6.07 ± 2.07 | 2.50 ± 0.55 |
| All You Ever Wanted | The Black Keys | 2008 | 59 | 6.50 ± 1.64 | 3.33 ± 0.82 |
| Fast tempo | | | | | |
| Old Yellow Bricks | Arctic Monkeys | 2007 | 135 | 7.00 ± 1.10 | 6.67 ± 0.82 |
| Satisfaction | Rolling Stones | 1965 | 136 | 6.67 ± 0.82 | 7.67 ± 1.03 |
| Hideaway | Kiesza | 2014 | 123 | 6.33 ± 1.03 | 6.67 ± 0.82 |
| What Is Love | Haddaway | 1993 | 124 | 6.67 ± 1.75 | 7.67 ± 0.52 |
| Fever | The Black Keys | 2014 | 128 | 6.17 ± 1.47 | 6.83 ± 0.98 |

Table 2

*Peak Physiological Responses to Incremental Treadmill Running, mean ± SD (N = 13)*

| Variables | Rest | Max |
|---|---|---|
| Treadmill Speed ($km \cdot hr^{-1}$) | 0 ± 0 | 20 ± 2 |
| $\dot{V}O_2$ ($L \cdot min^{-1}$) | 0.38 ± 0.09 | 4.34 ± 0.50 |
| $\dot{V}O_2$ ($ml \cdot kg \cdot min^{-1}$) | 5.4 ± 1.1 | 61.6 ± 6.1 |
| $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 0.36 ± 0.09 | 5.12 ± 0.53 |
| RER | 0.95 ± 0.13 | 1.18 ± 0.07 |
| HR ($b \cdot min^{-1}$) | 57 ± 9 | 196 ± 7 |
| $\dot{V}_E$ ($L \cdot min^{-1}$) | 11.7 ± 2.9 | 155 ± 20.8 |
| $V_T$ (L) | 0.84 ± 0.24 | 2.74 ± 0.38 |
| $f_R$ ($br \cdot min^{-1}$) | 14.6 ± 2.9 | 58.7 ± 10.1 |
| $T_{TOT}$ (s) | 4.4 ± 1.1 | 1.0 ± 0.2 |
| $RPE_{CR10}$ | 0 ± 0 | 10 ± 1 |

*Note*. $\dot{V}O_2$, $O_2$ uptake; $\dot{V}CO_2$, $CO_2$ output; RER, respiratory exchange ratio; HR, heart rate; $\dot{V}_E$, minute ventilation; $V_T$, tidal volume; $f_R$, respiratory frequency; $T_{TOT}$, respiratory duty cycle; $RPE_{CR10}$, rating of perceived exertion.

Table 3

*Descriptive Statistics for all Dependent Variables Recorded during Exercise Bouts (M ± SD)*

| | EFFORT 1 | | | EFFORT 2 | | | EFFORT 3 | | | EFFORT 4 | | | EFFORT 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slow | Fast | Control | Slow | Fast | Control | Slow | Fast | Control | Slow | Fast | Control | Slow | Fast | Control |
| $\dot{V}O_2$ ($L \cdot min^{-1}$) | 3.37 ± 5.56 | 3.39 ± 5.26 | 3.22 ± 6.91 | 3.27 ± 5.64 | 3.32 ± 5.26 | 3.13 ± 6.38 | 3.27 ± 5.92 | 3.32 ± 5.59 | 3.12 ± 7.00 | 3.30 ± 5.78 | 3.33 ± 5.56 | 3.16 ± 5.80 | 3.31 ± 6.03 | 3.30 ± 5.80 | 3.14 ± 5.31 |
| $\dot{V}O_2$ (%max) | 78 ± 10 | 79 ± 12 | 74 ± 12 | 76 ± 11 | 77 ± 13 | 72 ± 12 | 76 ± 12 | 77 ± 13 | 72 ± 13 | 76 ± 11 | 77 ± 13 | 73 ± 11 | 76 ± 12 | 77 ± 14 | 73 ± 10 |
| $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 3.37 ± 5.64 | 3.41 ± 5.80 | 3.34 ± 7.22 | 3.16 ± 5.68 | 3.20 ± 5.64 | 3.12 ± 6.15 | 3.12 ± 6.00 | 3.19 ± 5.93 | 3.09 ± 6.65 | 3.16 ± 5.84 | 3.19 ± 5.92 | 3.12 ± 5.81 | 3.15 ± 6.13 | 3.15 ± 6.21 | 3.09 ± 5.69 |
| HR ($b \cdot min^{-1}$) [c] | 171.50 ± 6.97 | 171.38 ± 5.85 | 171.85 ± 9.27 | 175.46 ± 7.99 | 175.15 ± 6.91 | 175.46 ± 9.66 | 179.54 ± 7.73 | 178.69 ± 6.50 | 179.08 ± 10.02 | 181.00 ± 8.24 | 181.08 ± 6.59 | 181.46 ± 9.88 | 183.00 ± 8.05 | 182.08 ± 7.24 | 182.92 ± 9.17 |
| $\dot{V}_E$ ($L \cdot min^{-1}$) [c] | 94.13 ± 25.38 | 93.38 ± 24.67 | 93.87 ± 22.93 | 91.84 ± 24.59 | 93.93 ± 21.41 | 93.96 ± 21.45 | 96.65 ± 25.13 | 95.99 ± 24.28 | 96.48 ± 22.21 | 98.77 ± 25.85 | 98.14 ± 24.73 | 98.04 ± 21.39 | 99.79 ± 26.18 | 99.51 ± 25.21 | 99.04 ± 23.00 |
| $V_T$ ($L \cdot min^{-1}$) [c] | 2.41 ± 0.32 | 2.48 ± 0.29 | 2.43 ± 0.26 | 2.25 ± 0.35 | 2.17 ± 0.26 | 2.25 ± 0.29 | 2.17 ± 0.30 | 2.21 ± 0.29 | 2.23 ± 0.29 | 2.14 ± 0.30 | 2.19 ± 0.30 | 2.08 ± 0.24 | 2.13 ± 0.28 | 2.16 ± 0.29 | 2.03 ± 0.27 |
| $f_R$ ($br \cdot min^{-1}$) [c] | 39.17 ± 9.36 | 37.83 ± 8.96 | 38.71 ± 8.31 | 41.11 ± 10.24 | 43.10 ± 6.56 | 42.09 ± 8.90 | 44.73 ± 10.00 | 43.56 ± 9.52 | 43.71 ± 9.32 | 46.65 ± 11.50 | 44.97 ± 9.66 | 47.10 ± 7.93 | 47.16 ± 11.89 | 46.48 ± 10.59 | 48.60 ± 8.40 |
| $T_{TOT}$ (s) [c] | 1.67 ± 0.50 | 1.64 ± 0.48 | 1.69 ± 0.45 | 1.60 ± 0.50 | 1.39 ± 0.25 | 1.56 ± 0.46 | 1.48 ± 0.47 | 1.42 ± 0.51 | 1.49 ± 0.45 | 1.43 ± 0.50 | 1.38 ± 0.52 | 1.35 ± 0.27 | 1.42 ± 0.49 | 1.35 ± 0.54 | 1.30 ± 0.25 |
| $RPE_{CR10}$ [c] | 4.77 ± 1.09 | 4.69 ± 1.25 | 4.69 ± 1.18 | 4.77 ± 1.17 | 5.15 ± 1.41 | 5.08 ± 1.32 | 5.38 ± 1.39 | 5.62 ± 1.45 | 5.31 ± 1.38 | 5.77 ± 1.36 | 5.77 ± 1.48 | 5.85 ± 1.41 | 5.85 ± 1.34 | 6.08 ± 1.80 | 6.23 ± 1.54 |

*Note.* $\dot{V}O_2$, $O_2$ uptake; $\dot{V}CO_2$, $CO_2$ output; HR, heart rate; $\dot{V}_E$, minute ventilation; $V_T$, tidal volume; $f_R$, respiratory frequency; $T_{TOT}$, respiratory duty cycle; $RPE_{CR10}$, rating of perceived exertion. [a] = significant condition x time interaction, [b] = significant main effect of condition, [c] = significant main effect of time.

Table 4

*Descriptive Statistics for all Dependent Variables Recorded during Recovery Periods (M ± SD)*

| | RECOVERY 1 | | | RECOVERY 2 | | | RECOVERY 3 | | | RECOVERY 4 | | | RECOVERY 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Slow | Fast | Control | Slow | Fast | Control | Slow | Fast | Control | Slow | Fast | Control | Slow | Fast | Control |
| $\dot{V}O_2$ (L.min-1) | 1.06 ± 0.25 | 1.10 ± 0.24 | 0.99 ± 0.32 | 1.09 ± 0.27 | 1.11 ± 0.27 | 1.00 ± 0.34 | 1.06 ± 0.36 | 1.11 ± 0.27 | 1.03 ± 0.34 | 1.09 ± 0.30 | 1.16 ± 0.33 | 1.03 ± 0.31 | 1.11 ± 0.30 | 1.11 ± 0.29 | 1.02 ± 0.31 |
| $\dot{V}CO_2$ ($L \cdot min^{-1}$) | 1.18 ± 0.30 | 1.23 ± 0.30 | 1.16 ± 0.40 | 1.18 ± 0.33 | 1.19 ± 0.32 | 1.13 ± 0.41 | 1.13 ± 0.43 | 1.19 ± 0.31 | 1.15 ± 0.43 | 1.16 ± 0.35 | 1.23 ± 0.36 | 1.15 ± 0.46 | 1.17 ± 0.35 | 1.19 ± 0.34 | 1.14 ± 0.42 |
| HR ($b \cdot min^{-1}$)[a, c] | 107.00 ± 8.74 | 106.69 ± 6.38 | 104.31 ± 10.42 | 110.92 ± 7.57 | 114.15 ± 8.13 | 112.85 ± 12.19 | 119.08 ± 8.54 | 120.54 ± 8.18 | 120.92 ± 12.47 | 125.77 ± 12.90 | 124.31 ± 9.52 | 126.92 ± 13.02 | 129.31 ± 11.21 | 128.38 ± 9.67 | 127.77 ± 12.75 |
| $\dot{V}_E$ ($L \cdot min^{-1}$)[c] | 36.15 ± 10.57 | 37.92 ± 11.34 | 36.30 ± 11.08 | 36.74 ± 11.49 | 38.54 ± 11.66 | 37.98 ± 11.08 | 36.60 ± 12.64 | 40.05 ± 12.31 | 39.74 ± 12.95 | 38.92 ± 12.10 | 41.44 ± 12.70 | 40.48 ± 14.63 | 39.68 ± 11.87 | 41.27 ± 12.60 | 41.84 ± 15.01 |
| $V_T$ ($L \cdot min^{-1}$)[c] | 1.36 ± 0.29 | 1.40 ± 0.22 | 1.40 ± 0.23 | 1.31 ± 0.27 | 1.34 ± 0.24 | 1.35 ± 0.28 | 1.25 ± 0.25 | 1.31 ± 0.22 | 1.37 ± 0.27 | 1.29 ± 0.25 | 1.34 ± 0.27 | 1.31 ± 0.25 | 1.25 ± 0.23 | 1.26 ± 0.25 | 1.33 ± 0.24 |
| $f_R$ ($br \cdot min^{-1}$)[c] | 26.55 ± 5.39 | 27.11 ± 5.86 | 26.19 ± 6.91 | 28.37 ± 29.37 | 29.37 ± 8.66 | 29.10 ± 6.91 | 29.26 ± 7.62 | 30.81 ± 7.99 | 29.74 ± 9.75 | 30.73 ± 8.91 | 31.65 ± 9.01 | 31.47 ± 11.37 | 32.26 ± 9.58 | 33.15 ± 9.04 | 32.28 ± 11.99 |
| $T_{TOT}$ (s)[c] | 2.54 ± 0.60 | 2.34 ± 0.58 | 2.59 ± 0.78 | 2.44 ± 0.74 | 2.32 ± 0.95 | 2.48 ± 0.91 | 2.39 ± 0.74 | 2.23 ± 0.91 | 2.39 ± 0.84 | 2.30 ± 0.76 | 2.17 ± 0.87 | 2.29 ± 0.75 | 2.22 ± 0.81 | 2.03 ± 0.72 | 2.30 ± 0.91 |
| ENT (%) | 20.77 ± 15.53 | 19.23 ± 10.38 | - | 20.00 ± 12.25 | 20.00 ± 12.25 | - | 17.69 ± 12.35 | 20.77 ± 10.38 | - | 26.15 ± 13.87 | 26.15 ± 17.10 | - | 24.62 ± 13.30 | 16.92 ± 13.77 | - |
| FS[b] | 2.08 ± 1.19 | 2.54 ± 1.05 | 1.46 ± 1.51 | 2.08 ± 1.19 | 2.54 ± 0.88 | 1.54 ± 0.97 | 2.08 ± 1.50 | 2.46 ± 0.97 | 1.54 ± 1.20 | 2.0 ± 1.35 | 2.54 ± 1.71 | 1.62 ± 1.12 | 2.08 ± 1.55 | 2.69 ± 1.49 | 1.69 ± 1.75 |
| FAS[c] | 3.46 ± 0.97 | 4.15 ± 0.69 | 3.69 ± 0.75 | 3.69 ± 1.18 | 4.00 ± 0.71 | 3.77 ± 1.09 | 3.92 ± 1.26 | 3.85 ± 1.07 | 3.85 ± 0.99 | 3.54 ± 1.27 | 4.15 ± 1.14 | 3.92 ± 1.12 | 3.54 ± 1.33 | 3.92 ± 0.86 | 3.23 ± 1.36 |

*Note.* $\dot{V}O_2$, $O_2$ uptake; $\dot{V}CO_2$, $CO_2$ output; HR, heart rate; $\dot{V}_E$, minute ventilation; $V_T$, tidal volume; $f_R$, respiratory frequency; $T_{TOT}$, respiratory duty cycle; ENT, proportion of respite time spent entrained; FS, Feeling Scale; FAS, Felt Arousal Scale. [a] = significant condition x time interaction, [b] = significant main effect of condition, [c] = significant main effect of time.

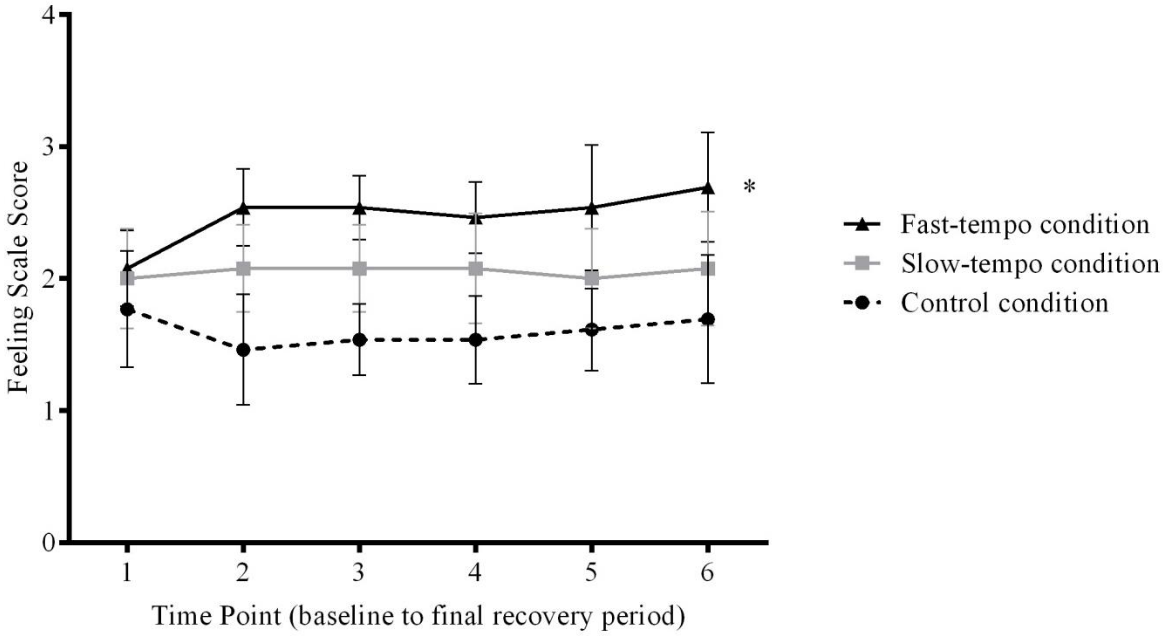


**Fig. 1.** Significant main effect of condition for Feeling Scale scores. *$p$ = .010; fast-tempo music > control condition.

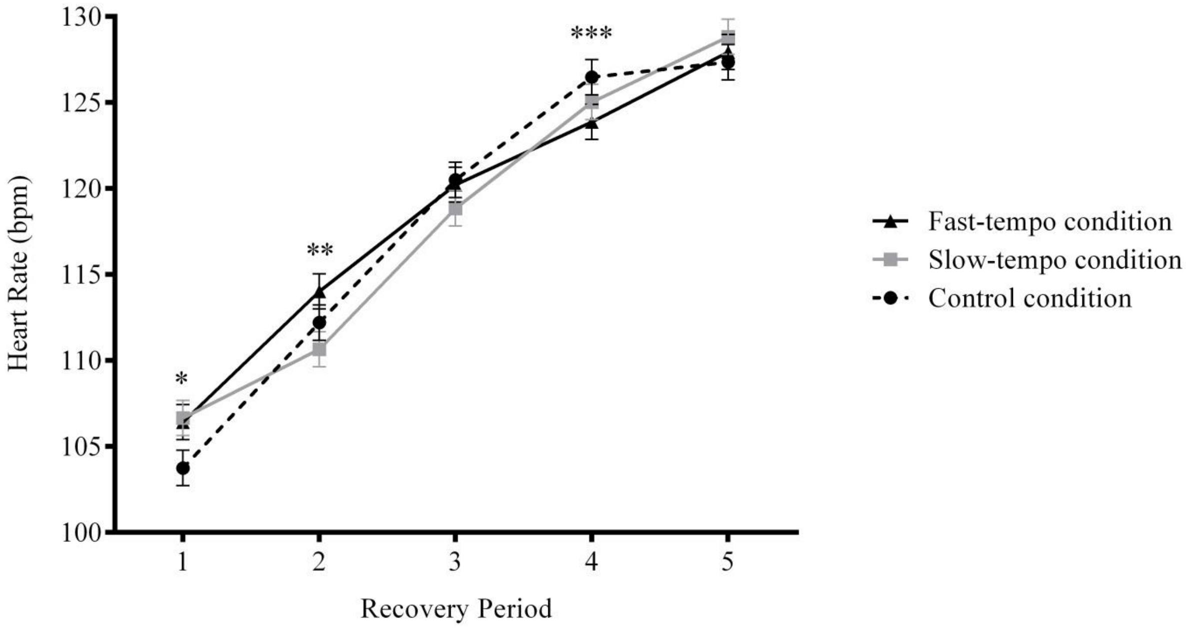


**Fig. 2.** Significant condition x time interaction effect for heart rate during recovery ($p$ = .034). * control condition < slow- and fast-tempo condition, ** slow-tempo < fast-tempo, *** fast-tempo < control condition.