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Music in the exercise domain: a review and synthesis (Part I)

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Since a 1997 review by Karageorghis and Terry, which highlighted the state of knowledge and methodological weaknesses, the number of studies investigating musical reactivity in relation to exercise has swelled considerably. In this two-part review paper, the development of conceptual approaches and mechanisms underlying the effects of music are explicated (Part I), followed by a critical review and synthesis of empirical work (spread over Parts I and II). Pre-task music has been shown to optimise arousal, facilitate task-relevant imagery and improve performance in simple motoric tasks. During repetitive, endurance-type activities, self-selected, motivational and stimulative music has been shown to enhance affect, reduce ratings of perceived exertion, improve energy efficiency and lead to increased work output. There is evidence to suggest that carefully selected music can promote ergogenic and psychological benefits during high-intensity exercise, although it appears to be ineffective in reducing perceptions of exertion beyond the anaerobic threshold. The effects of music appear to be at their most potent when it is used to accompany self-paced exercise or in externally valid conditions. When selected according to its motivational qualities, the positive impact of music on both psychological state and performance is magnified. Guidelines are provided for future research and exercise practitioners.

Keywords: pre-task music; asynchronous music; synchronous music; post-task music

The authors have spent the last two decades systematically investigating the effects of music in exercise, sport and other physical activity contexts (e.g., physiotherapy rehabilitation). The proposed benefits of music in such contexts have intrigued researchers for over 40 years. The purpose of this two-part article is to review and synthesise the extant literature with a primary focus on exercise-related activities; Daniel Bishop produced a comprehensive review of the sport-related literature recently in the *Sport and Exercise Psychology Review* (2010). The authors will critically evaluate some of the assumptions and methods that have underpinned the work they have conducted with their principal collaborators (Bishop, Jones, Lane, Lim and Terry) and appraise the exercise-related studies since the 1997 review of Karageorghis and Terry. The present review will aim to identify important trends, provide recommendations for future research endeavours and spawn firm evidence-based principles for exercise practitioners.

We live in a time when technology has brought us closer to music than ever before, enshrining its role in our emotional and social lives (DeNora & Bergh, 2009).

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According to the available evidence, music captures attention, raises spirits, triggers a range of emotions, alters or regulates mood, evokes memories, increases work output, heightens arousal, induces states of higher functioning, reduces inhibitions and encourages rhythmic movement (Karageorghis, 2008; Lucaccini & Kreit, 1972; Terry & Karageorghis, 2011) – all purposes that have considerable application in the exercise domain.

Although there is an extensive corpus of literature addressing the benefits of music on exercise-related tasks, research prior to the mid-1990s was of variable quality and produced equivocal findings (see Karageorghis & Terry, 1997 for a review). These inconsistencies were attributed to methodological limitations and the lack of a guiding theoretical framework. Researchers were also insensitive to musical terminology, operated poor music selection protocols, chose inappropriate measures and failed to standardise important aspects of experimental protocol such as playing music at a consistent intensity (volume) and controlling when it was played in relation to the task.

While research over the past decade has overcome many of the earlier methodological shortcomings, there is a considerable challenge in summarising it succinctly owing to the wide range of research questions and methodologies that have been employed. Therefore in this review and synthesis it will be incumbent on the authors to draw general conclusions based upon a critical appraisal of ostensibly similar studies which nonetheless apply different experimental designs, musical stimuli and measures, and address a multitude of different questions.

The principal criteria for inclusion in this review are as follows: that the study in question incorporated a music-based intervention in an exercise setting to a single group with pre- and post-test scores, or to experimental and control groups. Qualitative (interview and observation-based) and theoretical papers are also included to complement the review of experimental or quasi-experimental studies. Only studies published in scientific journals employing peer review that use English as their primary language are included. Further, all the studies included post-date the previous review published in 1997 by Karageorghis and Terry. Any studies that were not included in this former review owing to the publication lag ($k = 9$) have been included in the present review.

Conceptual approaches

The inaugural conceptual framework to predict the effects of music in sport and exercise was developed by Karageorghis, Terry, and Lane (1999; see Figure 1). Its scope was limited to the *asynchronous* use of music; that is, when an individual makes no conscious effort to synchronise their movements to its rhythm. Four factors were thought to contribute to the *motivational qualities* of a musical piece. *Rhythm response* refers to the effects of musical rhythm, especially tempo (speed of music as measured in beats per min [bpm]). *Musicality* refers to the pitch-related elements of music such as harmony (how the notes are combined when played together) and melody (the tune). *Cultural impact* concerns the pervasiveness of the music within society or a sub-cultural group. Finally, *association* refers to the extra-musical associations that may be evoked. For example, the composition *Chariots of Fire* by Vangelis is often associated with Olympic glory.

Because rhythm response and musicality objectively denote audible properties of the musical stimulus, they are known as *internal factors* whereas cultural impact and association are referred to as *external factors*. In the field of psychomusicology, the terms *intrinsic and extrinsic*, *intrinsic and ecological*, and *congeneric and extrageneric* factors have been used in a similar manner (see North & Hargreaves, 2008). Music selections that exploit cultural and personal associations are likely to yield significant benefits, particularly in terms of cognitive and affective consequences. Although the *Rocky* example predominantly entails a cultural association, a personal association can occur when a piece of music reminds an exerciser about an aspect of their own lives that is emotionally significant (see e.g., Priest & Karageorghis, 2008). It is important to clarify that whereas it would be easy to confuse rhythm response with the innate predisposition of humans to synchronise their movements to music rhythms (see Karageorghis & Terry, 1997, p. 56), the term was operationalised more generally in the 1999 model to refer to the stimulative effects of musical rhythm on the human body (cf. Hevner, 1937).

The four factors are hierarchically related, with rhythm response being the most important and association being the least important. The findings of both Crust (2008) and Priest and Karageorghis (2008) support the general structure of this hierarchy. Notably, the term *motivational qualities* was defined in terms of the beneficial consequences of listening to it. Such effects appear as outputs in the 1999 model, therefore motivating music is that which controls arousal, reduces perceptions of exertion and improves mood. Herein lies a criticism of the model: motivational music was also defined in terms that render it directly comparable with Hevner's (1937) definition of stimulative music, that is, with a fast tempo and prominent beat. Hence, while motivational music would be expected to heighten arousal, it would not lower it as the term 'arousal control' would suggest.

Ultimately, motivational music use was thought to promote two chronic benefits: increased exercise adherence among exercise participants and a more effective pre-event routine for athletes. The tenets of the model, particularly the four-factor structure of motivational qualities, were validated through the development of a

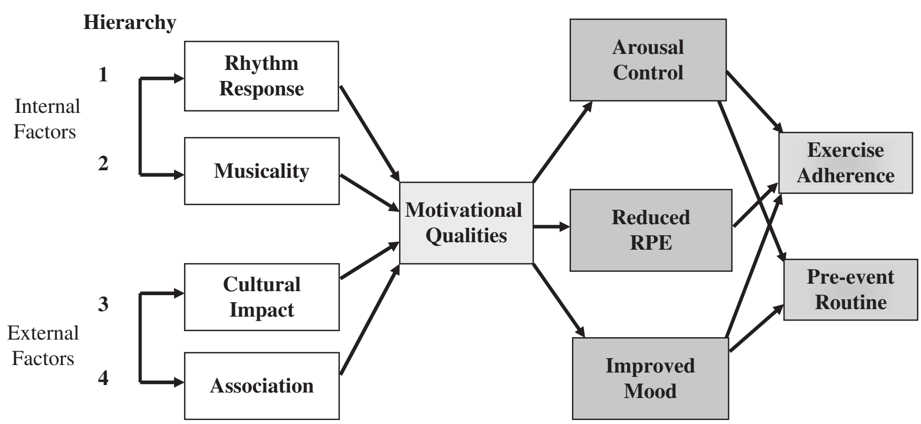

Figure 1. Conceptual framework for the prediction of responses to motivational asynchronous music in exercise and sport. (Adapted from Karageorghis, Terry, & Lane, 1999. Reproduced with permission from Taylor and Francis, http://www.tandfonline.com)

psychometric instrument, the Brunel Music Rating Inventory (BMRI; Karageorghis et al., 1999), which was designed as a tool to rate the motivational qualities of musical pieces. The BMRI was subsequently refined to enhance its psychometric properties and usability (BMRI-2; Karageorghis, Priest, Terry, Chatzisarantis, & Lane, 2006; BMRI-3; Karageorghis, 2008). Using the 1999 model as a lodestar, a redeveloped model was proposed in 2006 (see Figure 2), which featured a simplified structure and a more comprehensive list of consequences based on what the research in sport and exercise contexts was showing (Terry & Karageorghis, 2006). The latter model depicted the growing list of benefits that have been shown to accrue when physical activity is accompanied by appropriately selected music. Specifically, music has been found to exert a range of ergogenic (work-enhancing) and psychological effects.

An *ergogenic* effect is evident when music improves exercise performance by either delaying fatigue or increasing work capacity. Typically this effect results in higher-than-expected levels of endurance, power, productivity or strength (Karageorghis, 2008). In this sense, music can be thought of as a type of legal performance-enhancing drug. The *psychological* effects of music on exercise include the way in which music influences mood, emotion, affect (feelings of pleasure or displeasure), cognition (thought processes) and behaviour. There is a subcategory of psychological effects, referred to as *psychophysical effects*, which concerns the subjective perception of physical effort and fatigue (i.e., the psychological estimation of a physiological process). In the music and exercise literature, the sole psychophysical measure employed is Borg's Ratings of Perceived Exertion (RPE) scale; so psychophysical effects are synonymous with perceived exertion. Finally, the term *psychophysiological effects* refers to the physiological correlates of music's psychological effects (e.g., changes in heart rate [HR] or blood pressure).

The 2006 model was also notable for the inclusion of supplementary antecedents relating to the exerciser (personal factors) and the context (situational factors). Personal factors that may influence the effects of music include gender, age, personality type, commitment to exercise (i.e., infrequent vs. regular exercisers), fitness level and attentional style. Situational factors typically involve the exercise environment and specifics of exercise regimens. The pre-eminent music psychologist John Sloboda (2008) asserted that there is no 'vitamin model' that associates a

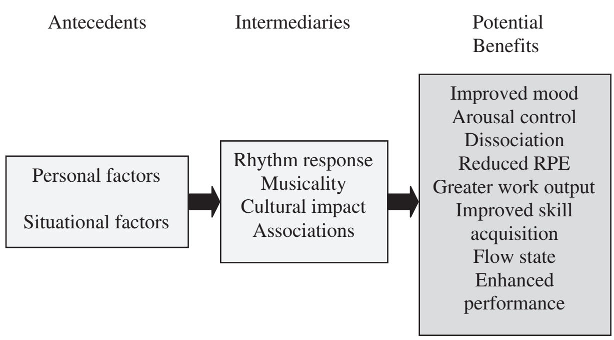

Figure 2. Conceptual framework for benefits of music in sport and exercise contexts. (Reproduced from Terry & Karageorghis, 2006, with permission from the Australian Psychological Society.)

prescribed psychological effect for a given piece of music. Music's influence is entirely contingent upon the listening context and the experiences and preferences of the listener.

Mechanisms used to explain the benefits of music in exercise

The mechanisms that underpin the effects of music are poorly understood at present, yet they are of seminal importance to establishing the longevity and authenticity of this branch of sport and exercise science research. Although the effects of music have been extensively tested, researchers have generally devoted insufficient attention to the underlying mechanisms. This may be because the instrumentation required (e.g., electroencephalograms, functional magnetic resonance imaging [*f*MRI] scanners, online respiratory analysis systems) is sufficiently cumbersome to detract from the effects of music as experienced in naturalistic settings (Karageorghis & Terry, 1997; Schwartz, Fernhall, & Plowman, 1990). Indeed, a portable *f*MRI scanner to assess neurophysiological responses to music in the exercise setting may be a decade or more away. Also, music is often experienced in a social context that cannot be easily created in experimental settings. There is an inherent difficulty associated with assessing an artistic stimulus in a scientific context; a problem that afflicts psychomusicology in general (Sloboda, 2008). With all of this in mind, what follows is what we do appear to know about the underlying mechanisms.

Attentional processing

It is thought that the limited capacity of the nervous system is relevant to the effects of music on attention (see Rejeski, 1985). The *afferent nervous system* transmits sensory impulses inwards to the central nervous system (brain and spinal column). Since the capacity of the afferent nervous system is limited (an equivalent concept to internet 'bandwidth'), sensory stimuli such as music can impede the physiological feedback signals associated with physical exertion. Hernandez-Peon (1961) explained that pleasurable stimuli promote electrical activity in one sensory pathway while inhibiting electrical activity, and thus the transmission of information, in another sensory pathway.

It is reported that the intensity of exercise determines the extent to which music can inhibit the processing of other sensory cues (Rejeski, 1985; Tenenbaum, 2001). At high intensity levels, physiological cues appear to dominate processing capacity due to their relative strength, while at the more moderate intensity levels of exercise, both internal (e.g., kinaesthetic) and external (e.g., music) cues can be processed in parallel. While the positive effects of music on how one feels may not have the power to alter the perceptions of fatigue when exercising at a very high intensity, music may change how one interprets or responds to sensations of high exertion (Hardy & Rejeski, 1989). In other words, although it is not possible to distract exercisers from the fatigue induced by high-intensity exercise, it is possible to change their perception of this fatigue towards a more positive evaluation; ostensibly music appears to 'colour' the interpretation of fatigue (Karageorghis et al., 2009).

Synchronous response to musical rhythm

'Rhythm response', which refers to an innate human predisposition to synchronise movement with musical rhythms, has been studied since the turn of the twentieth century (MacDougall, 1903) and there is a credible neuropsychological explanation for this tendency. Schneider, Askew, Abel, and Strüder (2010) reported commonalities between movement frequency during exercise and music tempo that appeared to be reflected by the frequency (approximately 3 Hz) of electroencephalographic delta activity in the brain. They argued that the brain's role as principal regulator of locomotion, neurovascular control and sensory integration explained the coincidence of music tempo and physiological processes. Specifically, there may be a 'pattern generator' as the basis for locomotor rhythmicity as is the case with invertebrates, fish and cats. Indeed, the neurologist Frank Wilson (1987, pp. 131–132) referred to a type of internal clock or pacemaker in the brain that is thought to regulate temporal functioning. Such a mechanism may serve to coordinate the incoming *afferent* nerve signals with their *efferent* counterparts that direct the muscles. Along similar lines, Clynes and Walker (1982) highlighted a property of the central nervous system called *time form printing*, which is the propensity to execute repetitive patterns of movement (e.g., running) with only the initial command requiring specific attention. Thus, once the shape and rate of the pattern have been established, attention can be directed elsewhere.

In recent years, *f*MRI work has shed more light on the possible seat of rhythm response in the brain. For example, Kornysheva, von Cramon, Jacobsen, and Schubotz (2010) reported the involvement of pre-motor and cerebellar brain sectors during preferred as opposed to non-preferred musical rhythms and indicated that activity in the ventral premotor cortex is enhanced by a preferred tempo. They concluded that this mechanism may facilitate the process of 'tuning in' to an appealing musical beat. It is thought that the *supplementary motor area* of the brain plays a leading role in both the perception of musical rhythm and the rhythmic ordering of motor tasks (Zatorre, Halpern, Perry, Meyer, & Evans, 1996). The synchronous use of music may also reduce the metabolic cost of exercise by promoting greater neuromuscular or metabolic efficiency (Roerdink, 2008, pp. 220–221). A regular kinaesthetic pattern may require less energy to replicate owing to the absence of minute adjustments within the kinetic pattern (see Smoll & Schultz, 1982) and a greater relaxation which comes from the precise expectancy of the forthcoming movement.

Relationship between exercise heart rate and music tempo

Survey-based data reported by Priest, Karageorghis, and Sharp (2004) revealed that musical rhythm has a stimulative effect on the human organism irrespective of any synchronisation. Hence, in addition to activating certain neural structures in a periodic way so as to promote rhythmical movement, music may cause a generic stimulation of those parts of the brain that govern arousal, namely the limbic and reticular activating systems. There has been scientific interest in the stimulative effects of music for over 150 years. For example, using then newly available techniques to measure brain potentials, Neher (1962) reported that percussion sequences caused muscle-twitching and heightened electrical activity in the brain.

In their 2008 review, pre-eminent social psychologists of music, Adrian North and David Hargreaves, assert a link between the stimulative properties of a piece of music (especially tempo and volume) and its function in different listening situations. The assertion was that, the more arousal a situation required, the more preference would be afforded to stimulative music; hence music selection is functional (see Rendi, Szabo, & Szabó, 2008). Psychomusicologists have provided evidence that corroborates North and Hargreaves' assessment. Over the last two decades researchers (e.g., Iwanaga, 1995a, b; Karageorghis, Jones, & Low, 2006) have advocated investigations that explore the association between physiological arousal (measured by HR) and preference for music tempo. The first attempts to chart this relationship are presented in the later subsection entitled 'Association between exercise intensity and music tempo'.

Emotional response to music

Scherer and Zentner (2001) identified three routes for emotion induction resulting from music listening: memory, empathy and appraisal. The memory route concerns the propensity of music to act as a trigger which causes the recollection of an emotive event, perhaps via subcortical mechanisms resilient to neural rewiring (LeDoux, 1996). Empathy relates to the listener's ability to recognise and identify with emotions as expressed by the performer, a more probable route for emotion induction when listening to a performer who is highly admired, or when the music itself is particularly expressive in emotional terms. The final route is appraisal wherein the listener evaluates the personal significance of a communicated emotion in terms of their own wellbeing.

Scherer and Zentner (2001) noted two peripheral routes to musically induced emotion. The first is proprioceptive feedback, whereby emotions can be partially induced by instigating the physiological responses with which they are associated. This route is described in terms of the *coupling* of internal rhythms with external drivers. The second peripheral route concerns facilitating the expression of pre-existing emotions through the loosening of emotional control typically exhibited in social contexts. Scherer (2004) expanded upon Scherer and Zentner's (2001) earlier work by asserting that music was more likely to evoke *aesthetic* emotions than *utilitarian* ones. Aesthetic emotions are akin to the *secondary* emotions (cf. Plutchik, 1994) which are acquired and dependent on cognitive evaluation. By contrast, utilitarian emotions are adaptive (necessary for our survival) and a direct response to emergency situations.

Empirical research findings

In order to make sense of such a large mass of apparently similar studies with subtle distinguishing features (type of music used, type of task, etc.) it was necessary to establish some form of delineation. This approach allows researchers to place their work on a road map, and more easily compare their findings to those of others. The structure adopted herein is based on previous review work (e.g., Karageorghis & Terry, 1997; Lucaccini & Kreit, 1972) and is synthesised according to five classifiers: (a) the congruence of music introduction with the task (pre-task, in-task and post-task); (b) the tasks themselves (intensity, duration and mode [e.g., cycling, walking etc.]); (c) participants (trained vs. untrained); (d) the purpose of the musical selection (i.e., sedation or stimulation); and finally (e) the measures employed (e.g., psychological, psychophysical, physiological, etc.).

Pre-task music

Studies investigating the effects of music used prior to a physical performance are typically focused on music's use as a stimulative or sedative agent. It is noteworthy that all such investigations employed experimenter-selected and not self-selected music. A modest number of studies have explored the application of music as a form of stimulant or sedative prior to a physical task (pre-task music). Both Pearce (1981) and Karageorghis, Drew, and Terry (1996) investigated the effects of stimulative and sedative music on grip strength. Sedative music yielded lower scores than a white noise control condition. However, only Karageorghis at al. found that stimulative music increased grip strength relative to the control. This discrepancy can be attributed to the fact that the latter piece of research followed a more rigorous methodological approach in response to criticism raised by Karageorghis and Terry (1997).

Hall and Erickson (1995) obtained a broadly similar result using a stimulative music condition (the *Rocky* theme) in apposition to a control condition (waiting for 1 min) prior to a 60 m dash task. The music condition led to faster times than the control. The music was also associated with increased levels of somatic anxiety (heart rate, muscle tension, respiration rate, etc.) rather than the cognitive dimension of anxiety. Increases in self-confidence are thought to accompany reductions in state anxiety and qualitative findings have shown that listening to a preferred musical composition may heighten self-confidence prior to circuit training (Priest & Karageorghis, 2008).

Both Yamamoto et al. (2003) and Eliakim, Meckel, Nemet, and Eliakim (2007) evaluated the impact of stimulative music heard prior to an all-out cycle sprint on a stationary bike. Yamamoto et al.'s participants listened to either slow or fast music for 20 min prior to completing the trial (no control condition was included) and neither condition influenced power output. Nonetheless, based on assay of the neurotransmitter norepinephrine (implicated in the fight-or-flight response), the researchers reasoned that the slower music lowered arousal during the listening period whereas the faster music elevated it. Eliakim et al. used only a stimulative music condition against a no-music control. The music did not exert an ergogenic effect, although it did raise HR prior to the task, indicating an increase in arousal. Both studies provide partial evidence that pre-task music can assist in preparing the body for a bout of high-intensity exercise.

In-task asynchronous use of music

Anaerobic endurance

When music is used as an accompaniment to short-duration tasks, it is most often introduced prior to the task in order to elicit optimal levels of activation. However, on occasion, music has been introduced concurrently with brief tasks. Notably, the majority of such studies focus on high-intensity exercise. Both Crust (2004a) and

Crust and Clough (2006) tested the effects of motivational music on a muscular endurance task that entailed holding a weight extended directly in front of the body at shoulder height. In both studies, the participants endured longer in the presence of music as opposed to the control condition. The former study is notable because it contrasted the effects of pre- and in-task music. The greatest endurance was recorded when both pre- and in-task music were used successively.

The latter study (Crust & Clough, 2006) was distinct in that it employed a drumbeat condition that was extracted from the motivational music condition. Participants demonstrated higher endurance when exposed to the motivational music as opposed to the drumbeat condition. It may be that the various constituents of music possess a collective impact that is diminished when it is altered (Sloboda, 2008); in particular, the lyrical content of music can enhance affect as well as provide positive affirmations or task-related verbal cues (e.g., Crust, 2008; Priest & Karageorghis, 2008). Hence, although the percussive and rhythmical elements of music are paramount in the exercise sphere, they appear to lose potency when isolated. Crust and Clough's study is one of the most noteworthy in the literature for the reason that they applied the logical step, in the light of mainstream musicological work, of inferring a mediating role of personality traits in music responsiveness in an exercise context.

Extraverts have been found to prefer stimulative music (e.g., McCown, Keiser, Mulhearn, & Williamson, 1997) which relates to Eysenck's (1967) assertion that extraverts have a tendency to seek greater stimulation from the external environment. Crust and Clough's findings indicated that there were associations between trait liveliness and rhythm response, and between trait sensitivity and musicality response. The premise of personality traits influencing music reactivity was strongly franked by the qualitative work of Priest and Karageorghis (2008) who reported that self-motivation may influence musical choice.

Using a similar task to that of Crust (2004a) and Crust and Clough (2006), Razon, Basevitch, Land, Thompson, and Tenenbaum (2009) tested the effects of self-selected music on the maintenance of grip pressure. Although the music elicited a 21% improvement in endurance when compared to a no-music control (304 s vs. 252 s), the experimenters expressed doubts over the consistency of the effect. It was also found that music exerted an inconsistent effect on RPE during the course of the squeeze. Unexpectedly, music appeared to lower RPE during the initial stages while having the opposite effect in the latter stages. Limitations associated with the experiment included the possibility that assessing RPE and attentional focus every 30 s in itself represented a distraction which may have distorted participants' responses. The participant pool consisted of the highly trained ($>$75 min exercise per day) and for this reason the results may not be entirely representative of the mainstay of the exercise population. Those habituated to exercising at acute intensities may have been less susceptible to dissociative strategies as associative strategies are almost unavoidable at higher intensities of exercise (Hutchinson & Tenenbaum, 2007).

Doiron, Lehnhard, Butterfield, and Whitesides (1999) tested the effects of loud, upbeat music (70–80 dB; 120 bpm) on the number of repetitions completed in a circuit of resistance exercises. Each station of the circuit consisted of 30 s of repetitions at 65% of one repetition maximum for that exercise (therefore a supramaximal effort). The presence of music had no influence on the number of repetitions performed. Nonetheless, the intense nature of the exercise is likely to have rendered the music less consequential (cf. Rejeski, 1985; Tenenbaum, 2001).

Pujol and Langenfeld (1999) reported that fast music (120 bpm) had no effect on performance or fatigue in a maximum-intensity cycling test lasting 30 s. In explaining the findings, the authors documented the acknowledged predominance of physiological as opposed to psychological cues at higher exercise intensities. However, a number of authors have detected a positive difference using similar tasks (Hutchinson et al., 2011; Koç & Curtseit, 2009; Rendi et al., 2008). Rendi et al. chose a maximal-intensity short-duration 500 m rowing ergometer trial accompanied by either slow- or fast-tempo excerpts from Beethoven's 7th Symphony. The quickest times were recorded in the fast-tempo condition. Interestingly, the slow-tempo music also resulted in faster completion times when compared to the control condition. A possible limitation of this study is that none of the participants reported previous use of music during training. Accordingly, the application of music may have elicited a novelty effect that would have subsequently diminished with repeated exposure. Koç et al.'s results were remarkably similar in that both and slow and fast pop music selections elicited superior performance (by virtue of various power indices) during a maximum-intensity cycle ergometer test.

Finally, Hutchinson et al. (2011) administered a motivational music condition (using the BMRI-2) during a Wingate anaerobic cycle ergometer test. They found that the music increased peak and mean power while also positively influencing affect and self-reports of task motivation. Nonetheless, RPE was unaffected, possibly due to the supramaximal nature of the task. Interpretation and comparison of the results is somewhat hindered by the fact that the music was introduced as the participants began to increase their pedal speed (i.e., approximately 20 s prior to the initiation of the test). It is of note that the authors timed the introduction of the music so that a specific segment of the musical piece used (characterised by a 'building momentum') would accompany the participants' increase in pedal cadence prior to the test proper. This description mirrors exactly the phenomenon of *segmentation* described by Priest and Karageorghis (2008) on the basis of interviews with exercise participants. Segmentation refers to the anticipation of a particularly motivational segment of a musical piece often characterised by a crescendo of drumming. The interviewees reported anticipating a heightened expenditure of effort during the segment, and this in itself would give cause for elevated arousal.

Low-to-moderate-intensity endurance tasks

In the majority of studies, music use has been associated with clear improvements in endurance performance at low-to-moderate intensities of exercise. For example, Yamashita, Iwai, Akimoto, Sugawara, and Kono (2006) tested the effects of favoured music on RPE during cycle ergometer work at low *and* moderate intensities. Relative to the control condition, the music reduced RPE at the low but not the moderate exercise intensity. This result is partly predicted by Rejeski's parallel processing hypothesis which states that, as exercise intensity increases, physiological cues (e.g., heart rate, respiration rate) predominate. However, other studies have reported a strong effect at moderate exercise intensities (e.g., Potteiger, Schroeder, & Goff, 2000; Szmedra & Bacharach, 1998). The 'favoured' pop music selected by the participants may not have been motivational as its tempi were, with one exception, outside the ideal 125–140 bpm band (Karageorghis et al., 2011). Furthermore, only eight participants were engaged, which renders the analyses underpowered.

White and Potteiger (1996) also tested the effects of various distractions on perceived exertion during a low-intensity cycle-ergometer task. Their experimental conditions comprised visual, auditory, and mixed auditory and visual distractions. The auditory distraction consisted of fast music. Generally, perceived exertion was lower in the mixed and audio conditions than in the visual condition, which consisted of films depicting stunt performances. Nevertheless, there was little difference between the control and auditory conditions, a result that defied expectations. Typical of experimental work of this era, little attention was given to the cultural appropriateness of the music selections. The authors only detail that upbeat music (140–145 bpm) was used. A further unconsidered aspect of the stimuli used is that the emotional content of the visual condition may have interacted in some way with the music when they were delivered concurrently (cf. Loizou & Karageorghis, 2009). The work of Potteiger et al. (2000) also focused on low-intensity cycle ergometer work. Fast jazz, slow classical and self-selected music reduced perceptions of exertion relative to a control condition. The main implication of this study is that music that is arbitrarily selected can still distract exercise participants from sensations of fatigue.

Dyrlund and Wininger (2008) examined the effects of preferred and non-preferred music during 20 min of treadmill exercise at low, moderate and high intensity levels. A between-subjects design was used wherein each of the nine experimental conditions (i.e., three music conditions × three exercise intensities) were administered to a different subsection of the sample on a single occasion only. The convention in such studies is to employ a within-subjects design; from a statistical standpoint, it is very difficult to identify differences among conditions using a between-subjects design when responses to music are measured. Unsurprisingly then, the music conditions did not elicit any clear effect on either RPE or enjoyment levels.

Miller, Swank, Manire, Robertson, and Wheeler (2010) also employed a 20-min treadmill test and measured RPE and enjoyment. The test began at an intensity of 75–85% $\dot{V}O_2$ max and an unorthodox control consisting of verbal dialogue (spoken word books) was selected in apposition to self-selected music. Despite working harder by virtue of faster heart rate, high oxygen uptake and minute ventilation, participants experienced greater enjoyment and lower perceptions of exertion in the music condition. The use of a dialogic condition is novel and possesses external validity, yet there was little standardisation of either condition. For example, the content of the spoken text was not systematically controlled.

Szmedra and Bacharach (1998) compared the effects of a classical music programme and a no-music control during moderate-intensity running. The music condition lowered heart rate, blood pressure and perceptions of exertion. Upon considering the possible mechanisms that led to these benefits, the researchers concluded that music allowed participants to relax and reduce their muscular tension, thereby increasing blood flow and muscle recovery. The reduction in RPE for music vs. no music was approximately 10%. This figure was replicated in a subsequent study by Nethery (2002), who also found that perceived exertion was lower under a music condition (self-selected, 'motivational') during treadmill running when compared to a video condition, a sensory-deprived condition (earplugs and opaque goggles) and a control. This result held at both moderate (50% $\dot{V}O_2$ max) and high (80% $\dot{V}O_2$ max) intensities. Notably, the researcher in this case confounded the music condition by including opaque goggles, presumably in an effort to render the music condition directly comparable with the sensory-deprived condition.

Elliott, Carr, and Savage (2004) exposed participants to motivational music during a 12-min cycle ergometer trial. Their approach was somewhat unorthodox in that they required participants to cycle at a constant rate determined by their ratings of perceived exertion (which remained constant at 13 on the 20-point scale). The motivational music condition increased pedalling distance over the control, which suggests the participants *were* working harder. The music condition also led to an increase in positive feelings, which the authors concluded may have partly explained the effects of the music on perceptions of exertion and performance. They also observed that the benefits of music in terms of lessening perceptions of exertion may have a pronounced effect on the success of an exercise programme undertaken by sport and exercise science undergraduates.

Higher-intensity endurance tasks

Tenenbaum et al. (2004) and Macone, Baldari, Zelli, and Guidetti (2006) assessed the effects of music on a treadmill test to volitional exhaustion. In the former study, music conditions consisted of rock, dance and inspirational music (music deemed to evoke inspirational associations, such as the *Rocky* theme). None of these conditions impacted upon endurance or perceptions of exertion. The experiment was repeated using an outdoor 2.2 km run and similar results ensued. The authors concluded that the high intensity of the running tasks overshadowed the effects of the accompanying music. This explanation is consistent with Rejeski's (1985) and Tenenbaum's (2001) theoretical predictions that physiological feedback dominates the capacity of the nervous system at very high exercise intensities. The instrumental piece of music that Macone et al. selected – Wim Merten's airy and virtuosic *Struggle for Pleasure* – may well have been one with higher motivational qualities for the female participants as they endured for longer in the music conditions whereas their male counterparts did not. Women also experienced greater fatigue in the music conditions, possibly associated with their greater exercise endurance, although no other Profile of Mood States factors were affected by the music intervention.

The participants in Crust's (2004b) study completed the Balke Walking Test on a treadmill. The task is *graded*, which means that work rate is increased incrementally until volitional exhaustion is reached. The conditions of familiar music, unfamiliar music and white noise (control) did not influence endurance. Crust's music selection procedure might be questioned on the basis that he only manipulated one of the motivational qualities of music: cultural impact, which is of less importance than rhythm response, for example. Furthermore, his design focused only on one aspect of cultural impact, namely familiarity (cf. Karageorghis et al., 1999). Hence, from a theoretical standpoint, the music manipulation he employed was likely to prove inconsequential in terms of physical performance outcomes.

Music conditions have consistently improved time to volitional exhaustion in ergometer trials (Atkinson, Wilson, & Eubank, 2004; Bharani, Sahu, & Mathew, 2004; Nakamura, Pereira, Papini, Nakamura, & Kokubun, 2010). In the former study, trance music (a melodic variant of dance) was used during a 10-km cycle time trial. The ergogenic effect was particularly evident during the first 3 km of the trial when perceptions of exertion were relatively low in comparison to the latter stages. This particular finding reinforces the general conclusion that music is more effective as an ergogenic aid at lower exercise intensities. Nakamura et al.'s trial was also conducted on a cycle ergometer at an intensity level known as *critical power*, which in this study was calculated on the basis of initial trials as an intensity that was expected to cause fatigue in each participant before the 10 min mark. Participants endured for longer when listening to preferred music as opposed to non-preferred music and the no-music control condition. Non-preferred music also led to greater endurance than the control. Further, RPE was higher when listening to non-preferred music as opposed to preferred music or no music. Despite these positive findings, it was notable that the researchers used musical terminology incorrectly (tempo and rhythm were mistaken for each other), employed too few participants ($N = 15$), and included a condition that lacked external validity (non-preferred music).

In the Bharani et al. study (2004), participants ran on a treadmill to volitional exhaustion while listening to either self-selected music or no music. Participants reported lower RPE under the music condition when running at submaximal intensities; no comparison appears to have been made close to the point of exhaustion. It should be noted that the self-selection of music represents a threat to the validity of Bharani et al.'s experiment as it may have alerted participants' attention to the nature of the study and thus influenced their behaviour to some extent via the medium of expectancy.

Lim, Atkinson, Karageorghis, and Eubank (2009) conducted a follow-up study in which music was played either in the first or second half of a 10-km cycle ergometer trial and experimental conditions were compared against a no-music control. It was hypothesised that music would exert greater influence on power output when introduced during the second half of the trial. However, results indicated the converse: the highest power output occurred in the early stages of the trial when music was played during the first 5 km. This result suggested that foreknowledge of the removal of music may have affected participants' pacing strategy. Indeed, the mere anticipation of music may serve a *priming* or stimulating function even in the absence of the actual music. Interview-based work by Priest and Karageorghis (2008) reported that exercise participants and non-elite athletes experience a stark sense of expectancy regarding forthcoming music and their preferred segments of these pieces.

As with Lim et al.'s (2009) design, Szabo, Small, and Leigh (1999) inverted music conditions at the halfway point. Specifically, music tempo was switched by using segments from fast and slow movements of Beethoven's 7th Symphony. Moving from a slow to a fast tempo led to a higher work rate than conditions which consisted of purely fast *or* slow music. This may have been a *contrast effect* (Kassin, Fein, & Markus, 2008, pp. 138–139) whereby fast music appeared more stimulating by virtue of its contrast with the preceding slower selections. Changes of music tempo may enhance motivation and work output, especially when work levels plateau or during the latter stages of an exercise session (cf. Lucaccini & Kreit, 1972).

Schie, Stewart, Becker, and Rogers' (2008) study was unusual in that the music condition, which consisted of a variety of pop tracks, did not influence the measures of perceived exertion, heart rate or plasma lactate. The null result may have been influenced by the unusual choice of music which comprised five of the 10 most popular pieces of all time by sales: this included a song about a massacre (*Sunday Bloody Sunday* by U2) and one about the sorry state of human existence (*Imagine* by John Lennon). A participant pool that was extremely heterogeneous in terms of age (18–40 years) and the failure to include a performance measure also limit the potential contribution of this study to the literature.

Trained participants

Young, Sands, and Jung (2009) examined the effects of music on the running performance of trained female soccer players of university age. Participants ran to volitional exhaustion on a treadmill under conditions of self-selected music or no music. The conditions exerted no effect on RPE or endurance. This study contributes to the evidence base that music may have a negligible impact during high-intensity activity. However, the study can be criticised on three grounds: the music was not selected using available technology (such as the BMRI or its derivatives), existing theory was overlooked, and the sample size of 15 rendered the study underpowered.

Two studies have tested the effects of music on trained and untrained participants during treadmill running (Brownley, McMurray, & Hackney, 1995; Mohammadzadeh, Tartibiyan, & Ahmadi, 2008) and both supported the notion that music is more beneficial for the untrained. The Brownley et al. study was more comprehensive in its scope as a range of exercise intensities (low–moderate–high) and music types (stimulative and sedative) were used. In the low- and high-intensity conditions, untrained participants experienced more positive feeling states in response to stimulative music than did their trained counterparts. The authors concluded that listening to stimulative music may benefit untrained runners yet prove counterproductive for trained runners. Also, the untrained participants demonstrated more positive feeling states upon cessation of exercise than the trained. Hence, the study indicates that less-trained exercisers may depend to a greater extent on the positive feeling states engendered by music. It is possible that the focus of trained exercisers rests on the tasks and specifics of their training, similar to the focus of competitive athletes.

Along similar lines, Mohammadzadeh et al. (2008) tested the effects of music on endurance and RPE during the Bruce Protocol (a graded treadmill test to the point of volitional exhaustion). Notably, the type of music used in the experimental condition was not specified by the authors, which constitutes a major study limitation (cf. Karageorghis & Terry, 1997). Nevertheless, both trained and untrained participants endured for longer in the music condition relative to the no-music control condition. It is of interest that only the untrained participants experienced lower perceptions of exertion in response to the music, a finding that highlights a possible distinction between the attentional strategies employed by the trained and the untrained. This study employed personal music devices (MP3 players) and the authors made a comment that relates to many studies in this field of research: the introduction of the music may have alerted the participants to the experimental hypothesis and thus altered their behaviour; that is, if the participants became aware that the purpose of the experiment was to assess the effects of music on endurance, they may have endured for longer in the presence of music to produce the 'expected result'.

Sedative music

Whereas the majority of studies apply motivational music or some equivalent, two experiments have employed sedative music during treadmill running. Hepler and Kapke (1996) asked college students to run for 10 min at a moderate intensity whereas Ghaderi, Rahimi, and Azarbayjani (2009) assessed endurance in a high-intensity (85% max HR) run. In the former study, music had no effect on breathing volumes (relative to the control condition) but did lower participants' heart rates. The authors concluded that music lowered cardiac stress thereby instilling a more relaxed psychological state. Ghaderi et al.'s sample comprised trained men and a motivational music condition was added. Motivational music promoted greater endurance relative to the relaxing music and a no-music control condition. Interestingly, the relaxing music appeared to lower RPE during the trial and cortisol (a biochemical marker of stress) 5 min after the test. The authors concluded that, while motivating music may enhance performance, relaxing music reduces arousal.

Music also plays a prominent role in low-intensity activities such as yoga and Pilates. North and Hargreaves (1996) reported that music preferences during aerobics and yoga classes differed markedly. During yoga, participants preferred a *moderate* level of complexity in music whereas in the more vigorous aerobics class they preferred music in a simple form and preference deteriorated with additional complexity. The complexity variable is determined by the amount of information in the music, for example a slow piece with a simple rhythm and a lack of orchestration would be classed as low in complexity.

Self-paced exercise

Studies in which the participants are given some degree of autonomy in directing their activity are valuable owing to their external validity and thus degree of generalisability. A number of studies tested the effects of stimulative music on self-paced aerobic exercise performance and found that music enhanced work output (e.g., Cohen, Paradis, & LeMura, 2007; Elliott, 2007; Matesic & Cromartie, 2002). In two such studies, although work output was enhanced, music did not influence perceived exertion (Edworthy & Waring, 2006; Elliott, Carr, & Orme, 2005). Matesic and Cromartie measured performance during a 20-min self-paced run on an indoor track with participants exposed to alternate 5-min segments of techno dance music and silence delivered using a portable music player. Faster lap times were recorded during the musical segments. Elliott et al. (2005) also permitted self-selection of exercise intensity and reported similar results, finding that both motivational and oudeterous (neutral in motivational terms; see Karageorghis et al., 1999) music increased the distance pedalled in a cycle trial when compared to the control. It is of interest that neither music condition raised perceptions of exertion relative to the control. Hence, with the aid of the music, the participants were unaware of their greater exertion. While motivational music has been shown to promote superior benefits to those provided by arbitrary selections, the clear implications of this study are that any music may exert an ergogenic and distractive effect during exercise under conditions that mirror those of recreational exercise (i.e., self-paced work). Elliott (2007) conducted a follow-up study with a similar design that incorporated a variety of music tempi (100, 140, 180 bpm). Measures of work rate and distance pedalled were higher under the fast and very fast music conditions, signalling an ergogenic effect. The affect and RPE results were not conclusive, with the music conditions generally improving affect (only significantly so in the slow music condition) and raising RPE (in the case of fast music only).

Cohen et al. (2007) used a self-paced cycle ergometer task which participants were allowed to cessate when ready or after 45 min, whichever was soonest. Listening to self-selected music led to an increase in pedal rate of 3 rpm and increased volitional endurance by 1 min although only the former result reached significance. Edworthy and Waring (2006) tested effects of tempo (slow vs. fast) and intensity (quiet vs. loud) on the self-selected speed of treadmill running during 10-min trials. Fast musical accompaniment led to faster running speeds than either slow music or white noise (control condition). No differences were reported in terms of perceived exertion, which may imply a flaw in the measure as the participants worked harder in the two fast music conditions, a result that mirrors that reported by Elliott et al. (2005). The propensity of music to motivate individuals without them being consciously aware of the greater workload is noteworthy. All four of the music conditions improved feeling states relative to the control. However, the fast music conditions exerted a much larger effect. An interaction effect was reported in relation to the performance measure: whereas music volume exerted no ergogenic effect at the slower tempo, loud fast music led to speed increases when compared to loud slow music.

The work of Becker et al. (1994) is somewhat atypical as, although a 2 min bout of exercise was used, the cycling task was of a low intensity with participants free to cycle at their own pace. Nevertheless, this study is of interest as the self-selected movement tempo mirrors the behaviour of exercisers outside of the laboratory setting. The distance ridden was measured under conditions of stimulative and sedative music. Participants were bracketed by age range into three groups: children (9–11 years), adults (18–55 years), and older adults (60–80 years). Both music conditions (stimulative and sedative) were associated with significant increases in distance cycled compared to a white noise control condition (in children and adults). Of particular interest is the fact that ergogenic effects were found whether the music was presented prior to *or* during the task, although music used during the task elicited higher mean distances (1.00 miles) than music used before the task (0.91 miles), a result that mirrors that of Crust (2004a). This finding led the authors to conclude that the performance-enhancing properties of music cannot be explained purely by attentional distraction, but are also related to changes in affective and/or motivational states. The absence of an ergogenic effect in the seniors group indicates that the music selections may have been age-inappropriate (the stimulative selection was a 1980s pop track).

A follow-up study by Becker, Chambliss, Marsh, and Montemayor (1995) focused exclusively on the senior participant group and used an indoor walking task along with age-appropriate mellow and frenetic music. The music conditions failed to influence walking distance, which may have been due in part to the short 90 s measure used, which renders the test somewhat arbitrary and lacking in ecological validity.

Waterhouse, Hudson, and Edwards' (2010) study adds an interesting twist to the lineage of self-paced work. Participants cycled on an ergometer three times for 25 min, listening to a selection of pop music that was either played at the correct tempo, reduced in tempo by 10%, or raised by 10%. As the tempo increased, participants cycled further, pedalled faster and experienced more enjoyment, yet higher perceptions of exertion. Although the participants were not instructed to synchronise their movements with the tempi of the music, their performance does imply some possibility of a synchronisation effect in that their pedal cadence increased and decreased in line with alterations to the musical tempo. However, the experimenters selected a musical programme that included large variations in tempo, rendering the results somewhat problematic to interpret.

Among the most novel studies in the literature is that completed by Barwood, Weston, Thelwell, and Page (2009), who instructed their participants to complete a 15-min self-paced treadmill run. The intervention used was a combination of motivational music (BMRI-3 rated) and motivational films consisting of British sporting successes. The music and video intervention led participants to run further than the control condition without a corresponding increase in RPE. The work was limited by a small sample size ($N = 6$) and the use of a climate chamber to increase heat stress. Nonetheless, such threats to internal validity are assuaged somewhat by the external validity of the music and video combination, which suggests a fruitful avenue for future investigation (cf. Loizou & Karageorghis, 2009).

Association between exercise intensity and music tempo

Karageorghis and colleagues have undertaken an ongoing sequence of studies that has investigated the link between exercise heart rate and preferred music tempo (Karageorghis, Jones et al., 2006; Karageorghis, Jones, & Stuart, 2008; Karageorghis et al., 2011). The results of these studies confirm that faster music is preferred at higher exercise intensities but the relationship is more complex than the linear one posited by Iwanaga (1995a, b). Following questionnaire-based work with a variety of age groups, North and Hargreaves (1996) reported that the greatest discriminator of music preference across different situations was its arousal potential (akin to stimulative properties) of the preferred music. Individuals selected music so as to reinforce the level of arousal that was considered desirable for each environment. Thus, as a workout setting requires high arousal, stimulative music is preferred. This arousal potential hypothesis also implies a linear relationship as theorised by Iwanaga (1995a, b). However, when plotted on a graph, the exercise heart rate–music tempo preference relationship exhibits non-linear features, namely a dip and plateau (see Figure 3). The linear relationship depicted in Figure 3 is not an equivalence of tempo and HR as has been postulated by Iwanaga (1995a, b) but an interpretation based on a Karvonen calculation of exercise intensity for a healthy 21-year-old. It is therefore comparable to the hypothesised and observed trendlines. A key finding was that exercisers prefer a narrow tempo band of 125–140 bpm, which can be taken as evidence that music plays a specialised role in the exercise context.

Birnbaum, Boone, and Huschle (2009) used a steady-state exercise protocol that required participants to maintain a treadmill running speed of 8.8 km/hour. The conditions comprised fast music, slow music and a no-music control. Their results indicated that fast music increased several indices relating to heart and lung function

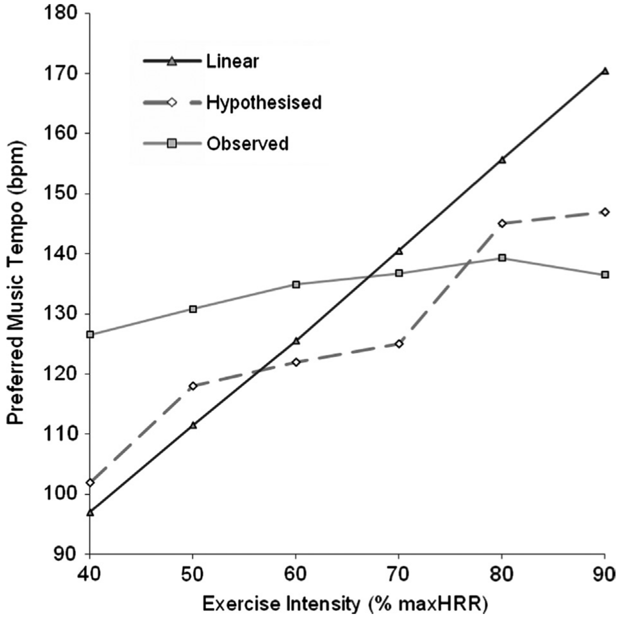

Figure 3. A comparison of the linear, hypothesised and observed relationships between exercise heart rate and music-tempo preference.
Note. The abbreviation % maxHRR denotes percentage of maximal heart rate reserve.

(minute ventilation, respiration rate, cardiac output) when compared to the other two conditions. Although the authors argued that fast music reduced cardiovascular efficiency, the findings indicate that, in concert with theoretical predictions, fast music heightened participants' physiological arousal. Furthermore, the steady state may have represented a different level of exercise intensity for each participant; some may have found it intense while others may have found it extremely easy. It is probable that some of the runners responded to the faster music by desiring to run at a faster speed, which the test conditions did not allow. Along similar lines, Waterhouse et al. (2010) reported that participants increased or decreased their pedalling cadence in line with an increment or decrement in music tempo. These effects could not be attributed entirely to synchronisation, hence the relationship between tempo and exercise intensity via psychomotor arousal is implicated.

Summary

In the first instalment of this two-part article we have introduced key concepts and critically evaluated extant theoretical approaches to the study of the effects of music in exercise. We have explored the mechanisms used to explain the effects of music on exercisers and reviewed empirical work concerning the use of pre-task music and in-task asynchronous music. Pre-task music can be used to heighten exercisers' activation for an impending bout of exercise but has not been used as a sedative in exercise-related research. It is suggested that despite the anxiolytic properties of music being relevant in the sport domain (see e.g., Bishop, 2010), they do not appear to be in the exercise domain (i.e., people do not get too anxious about exercising).

The mainstay of empirical work in this field has focused on the asynchronous use of in-task music and the review identifies a number of emergent trends: (a) music reduces perceptions of effort at low-to-moderate intensities of exercise by $\sim$10%, but does not appear to do so beyond the anaerobic threshold owing to the dominating influence of physiological cues on attentional processes (cf. Rejeski, 1985; Tenenbaum, 2001); (b) reductions in perceptions of effort are not moderated by whether music is self-selected or experimenter-selected; (c) regardless of exercise intensity, music appears to enhance affect but the magnitude of enhancement is not consistent across studies (Edworthy & Waring, 2006; Hutchinson et al., 2011); (d) at all exercise intensities, but especially low-to-moderate intensities, music has an ergogenic effect across a range of exercise modalities (e.g., Elliott et al., 2005; Razon et al., 2009); and (e) the relationship between exercise heart rate and preference for music tempo appears to be curvilinear (cubic) in nature (Karageorghis et al., 2011). These trends are appraised in a general discussion that appears in Part II of this article, accompanied by recommendations for future research and guidelines for exercise practitioners.

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