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Music in the Exercise and Sport Domain:
Conceptual Approaches and Underlying Mechanisms

By

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"I like Lil Wayne, Jay-Z, a little bit of Ludacris, those guys ...that's who we listen to in Jamaica. As long as it's hot, we got it!"

Usain Bolt (World's fastest man)

Introduction – An Overview of Music in Exercise and Sport

Casual observers cannot help but notice the almost symbiotic relationship between music and physical activity that has emerged in the modern era. This relationship has been fueled by rapid development in the technology that underlies music delivery—from gramophone records to live internet streaming at the level of the individual—and a growing recognition that well-selected music can both enhance and enrich the experience of physical activity. In the exercise domain, music is harnessed to block negative bodily signals from entering focal awareness, elevate affective states, and as a rhythmic cue that can prolong physical effort. In the sport domain, music is used to prime athletes, expedite their recovery from training, engender a sense of cohesion in teams, and heighten the emotional experience of spectators.

This chapter will cover key concepts and theoretical frameworks that pertain to the study and application of music in exercise and sport. Among these will be a recent theoretical model that addresses the antecedents, moderators, and consequences of music use (Karageorghis, 2016), the dual-mode model of exercise-related affect (Ekkekakis, 2003, 2005), relevant models of information processing (Rejeski, 1985), attention (Tenenbaum, 2001), and the principles of rhythmic entrainment (Thaut, 2008). We will then explore putative underlying neurophysiological and psychophysiological mechanisms that pertain to exercise-related affect, the moderating influence of exercise intensity on attentional dissociation, and efficiency gains derived through auditory-motor synchronization. Recent studies will be briefly reviewed with an emphasis on the main implications for practice. The concluding section will recapitulate key messages from the extant literature and provide the scientist-practitioner with a range of evidence-based recommendations.

Underlying Concepts and Theories

In the exercise and sport domain, researchers have typically explored the *psychological*, *psychophysical*, *psychophysiological*, and *ergogenic* effects of music. *Psychological* effects entail the influence that music has on core affect (feelings of pleasure or displeasure) and emotion, cognition, and behavior. The *psychophysical* effects of music concern the perception of one's physical state; most often assessed using one of Gunnar Borg's rating of perceived exertion (RPE) scales (e.g., Hutchinson, Karageorghis, & Jones, 2015; Lim, Karageorghis, Romer, & Bishop, 2014). *Psychophysiological* effects pertain to the impact of music on physiological functioning (e.g., heart rate, oxygen uptake, and blood lactate). Music has an *ergogenic* effect when it inspires higher than expected power output, endurance, or productivity.

A theory and accompanying model founded on the principles of embodied music interaction were recently advanced to predict the effects of music in the exercise and sport domain (Karageorghis, 2016; see Figure 1). The model is instructive rather than mechanistic in nature and provides the scientist-practitioner with a holistic visualization of the relationships identified by researchers in this context. The musical factors are referred to as "antecedents" because they precede our responses to the "musical whole" and are divided into two categories: *intrinsic* factors relate to the constituent components of music (e.g., rhythmic and harmonic features) and *extrinsic* factors relate to contextual associations of the sound (i.e., how they relate to a particular setting, situation, or set of circumstances). Moreover, the musical factors are set in a hierarchical structure; the intrinsic factors are suggested to be more influential than the external factors in determining how an individual will respond to a piece of music in exercise and sport settings.

Insert Figure 1 about here

There are a number of personal and situational factors that are proposed to moderate how a person responds to a piece of music. In contrast to the musical factors, the personal and situational factors are not arranged in a hierarchy owing to a lack of empirical research that would inform a hierarchical structure. The use of music in the exercise and sport context should comply with, or be carefully selected in accordance with, the tasks and specifics of a session. Accordingly, there is a reciprocal relationship between the personal and situational factors, which is in accord with the principles of embodied music interaction.

Personal factors such as musical preferences and attentional style (i.e., associator vs. dissociator) interact with the situational factors to determine an individual's response to music. To illustrate, an exerciser might display a preference for slow, calming music when participating in a Pilates class but prefer fast, uplifting music when participating in a Boxercise class, owing to the differing exercise intensities involved (a task-related factor). Along similar lines, associators are likely to use music as a type of metronome with which to regulate their movement patterns (a task-related factor) should the beat coincide with their intended work rate (Hutchinson & Karageorghis, 2013).

The consequences refer to the main outcomes associated with music use in the exercise and sport domain. The strongest and most consistent sets of consequences appear first (i.e., psychological and psychophysical consequences are by far the most frequently reported). Researchers have indicated that many of the consequences can be experienced in tandem. For example, well-selected music can result in a more positive affective state that is coupled with elevated work output (Elliott, Carr, & Savage, 2004). The outcomes experienced by exercisers or athletes will influence their future selection decisions and this is depicted in the model by feedback loops from the consequences to the musical factors via the moderators (see Figure 1).

Another conceptual framework that is pertinent to the study of music in the exercise and sport domain is the dual-mode model (Ekkekakis, 2003, 2005), which was proposed to delineate the relationship between exercise intensity and affective responses. A central tenet of the model is that the intensity of exercise should be defined according to an individual-specific metabolic marker, such as the ventilatory threshold. This point is reached when individuals start to produce more carbon dioxide than the amount of oxygen that they consume and is associated with a host of physiological changes (e.g., increased respiration rate and accumulation of lactic acid).

The model postulates that affective responses to exercise are mediated by the interplay of two factors: (a) cognitive factors originating primarily in the frontal cortex and (b) interoceptive cues from a variety of receptors that are stimulated by exercise-induced physiological changes (Ekkekakis, 2003). Affective responses to exercise below the ventilatory threshold are driven primarily by cognitive factors and are generally positive. When people exercise at intensities proximal to this threshold, affective responses exhibit large inter-individual variability, with some individuals reporting increases and others decreases in pleasure. Finally, at intensities above the threshold, interoceptive cues gain salience and affective responses exhibit declines in most individuals (Ekkekakis, 2003, 2005). Findings from recent research support the notion that well-selected music can enhance the affective responses of those exercising at intensities proximal to and even higher than the threshold (e.g., Jones, Karageorghis, & Ekkekakis, 2014).

Collectively, the theoretical propositions of Rejeski (1985) and Tenenbaum (2001) support the notion that sensory information is processed in parallel channels rather than in sequence. A distinction can be made between *perception* (i.e., all sensory information that can be attended to) and *focal awareness* (i.e., the channel that one does attend to; see Rejeski, 1985). In addition, strategies employed by individuals to cope with the demands of exercise can be classified as either *internal/associative* or *external/dissociative*. The former are employed when an individual attempts to cope *directly* with feelings of exertion, whereas the latter are employed when individuals attempt to shift their attention toward external stimuli (Tenenbaum, 2001). This helps to regulate perceptions of exertion by occupying the limited channel capacity that is available to focal awareness (Rejeski, 1985).

At low exercise intensities, individuals are able to voluntarily shift their attentional focus toward external cues (e.g., background music) or internal physiological processes (e.g., respiratory rate; Tenenbaum, 2001) and the perception of physical exertion is generally low (Rejeski, 1985). However, as the intensity of exercise increases, there comes a point at which internal physiological cues become overwhelming and an individual's focus automatically shifts internally. Consequently, it becomes very hard to manipulate perceived exertion when an individual is exercising beyond this critical level of intensity (Rejeski, 1985).

The principles of rhythmic entrainment and empirical investigation of this phenomenon provide the scientist-practitioner with a greater understanding of how bodily processes (e.g., respiratory rate) and motor patterns are influenced by music (Thaut, 2008). *Entrainment* refers to the "locking" of frequencies between two oscillating bodies (i.e., bodies that fluctuate periodically or rhythmically; Thaut, McIntosh, & Hoemberg, 2015). Musical rhythms can influence the movement patterns and bodily pulses (e.g., heart/respiratory rate) of individuals through entrainment to the periodicities in the rhythmic sequence, even in the absence of conscious effort (Hutchinson & Karageorghis, 2013; Thaut, 2008). Repetitive movements such as those required for running or cycling are particularly susceptible to rhythmic entrainment and if music is well selected with reference to desired pace and intensity, it can engender greater energy efficiency and work output (Karageorghis & Priest, 2012).

Putative Brain Mechanisms

The brain mechanisms by which music influences the psychological state and physiological responses of exercisers and athletes have only very recently begun to attract systematic investigation (e.g., Bigliassi, Karageorghis, Nowicky, Orgs, Wright, in press). The main reason for this is that motion renders most methods presently used to investigate human brain function inoperable. Likewise, exercise causes regional shifts in blood volume, making it difficult to disentangle the comparatively much smaller hemodynamic changes associated with the effects of music on attentional focus or affective state. Therefore, given the current methodological restrictions, this section presents an overview of hypotheses that are guiding ongoing research.

Emerging mechanistic ideas fall under three major themes. One approach focuses on music as an aesthetic stimulus that promotes pleasure, thereby also enhancing the affective experience of exercise. Neuroimaging studies have highlighted the nucleus accumbens—part of the main reward circuit of the brain—as an important structure of the mechanism by which music influences the affective state (Zatorre & Salimpoor, 2013). It is possible, based on converging evidence from non-exercise contexts, that one mechanism by which music may improve exercise performance is by raising the level of dopamine in the nucleus accumbens. Dopamine is a neurotransmitter that, among other functions, is believed to be involved in regulating the brain’s response to rewarding or pleasant stimuli.

A second perspective in the search for brain mechanisms considers music as a method for dissociating attention from the inherently unpleasant somatic sensations generated by strenuous exercise. This approach is motivated by applications of music mainly in clinical contexts in which exercise is a useful treatment or rehabilitation modality but may elicit excessive fatigue and unpleasant bodily symptoms. An example entails the use of music to improve the exercise experience of patients with chronic obstructive pulmonary disease who typically exhibit exercise-induced breathlessness (Lee, Desveaux, Goldstein, & Brooks, 2015).

Although studies had found increases in prefrontal brain activity during episodes of labored breathing (e.g., Higashimoto et al., 2011), the absence of a conceptual framework limits understanding of the functional significance of such findings. Nonetheless, based on earlier findings suggesting that the right dorsolateral prefrontal cortex—located under the front of the skull, approximately at the hairline—is involved in the modulation of pain during auditory distraction (Dunckley et al., 2007), authors have surmised that this brain region may play a similar role in episodes of physical exertion.

The application of near-infrared spectroscopy—a method used to track blood flow—to the study of brain responses during exercise is enabling researchers to study hemodynamic changes in the dorsolateral prefrontal cortex. In turn, this will allow the examination of the hypothesis that the effects of music on affective responses, perceptions of exertion, and exercise performance are mediated by corresponding changes in the activity of the dorsolateral prefrontal cortex (Bigliassi, León-Domínguez, Buzzachera, Barreto-Silva, & Altimari, 2015).

This line of inquiry has the potential to yield important implications for practice. Specifically, prior studies employing near-infrared spectroscopy of the dorsolateral prefrontal cortex during exercise have established that the oxygenation of this region increases at moderate intensities but drops to below-baseline levels shortly before a person reaches volitional exhaustion (Ekkekakis, 2009). One hypothesis that is being explored is that music may delay the increase in oxygenation, presumably as a result of moderate-intensity exercise being experienced as more pleasant or less unpleasant compared to a no-music condition.

Conceivably, there could be a shift of the entire oxygenation curve toward higher levels of intensity, resulting in a delay of the eventual decline in prefrontal oxygenation and thus improved maximal exercise performance. Alternatively, there may be a smaller increase in oxygenation at moderate intensities, presumably due to the lower level of experienced displeasure and therefore reduced need to cognitively control the displeasure, even in the absence of improved maximal exercise performance (see Figure 2). From the standpoint of application, this emerging research will help define the biological boundaries of an "efficacy zone," within which music can be expected to facilitate the cognitive control of unpleasant sensations associated with the rising exercise intensity.

Insert Figure 2 about here

A third perspective in the search for brain mechanisms focuses on the synchronization of the rhythms of music, bodily motion, and a postulated "neural resonance" (e.g., Large & Snyder, 2009). This perspective emerged from observations that listening to music causes remarkable synchronization not only in overt motor behavior (from finger tapping to running) but also across a wide range of physiological parameters, including the heart and respiratory rates (Trost & Vuilleumier, 2013). Functional neuroimaging investigations have shown that musical rhythm specifically engages motor areas of the brain, including the supplementary motor area, the premotor cortex, the cerebellum, and the basal ganglia (e.g., Kornysheva, von Cramon, Jacobsen, & Schubotz, 2010). While the linkage of this acoustic-motor coupling with affective or emotional experiences has yet to be fully elaborated, authors have speculated that the basal ganglia may play a crucial role as a bridge between motor function and emotion.

In the exercise domain, researchers have explored the notion of "intrinsic rhythms" that manifest themselves across different physiological and neurophysiological systems, arriving at suggestions that there is a predilection for 2 Hz across a range of locomotive and non-locomotive tasks and 3 Hz for running (Schneider, Askew, Abel, & Strüder, 2010). Practical outcomes of this line of research include the promotion of auditory-motor synchronization during exercise (e.g., by using apps that synchronize musical beat with running gait) can reduce perceptions of exertion and enhance mood.

Review and Synthesis of Empirical Research

The study of embodied music interaction in the field of exercise and sport has shown that music can be used to reduce unpleasant affective responses, ameliorate the effects of fatigue, regulate arousal, and enhance work output (Leman et al., 2013; Lim et al., 2014). The psychophysiological and ergogenic effects of music are generally studied in accordance with when the music is used: pre-task, in-task, and post-task (Karageorghis & Priest, 2012).

Pre-Task Music

The use of music as a pre-task strategy has not attracted a great deal of interest from researchers (see Karageorghis & Priest, 2012). The rationale underlying such use of music relates to the fact that sensory strategies manipulate an exerciser's or athlete's consciousness with consequent effects on performance (Bishop, Karageorghis, &

Loizou, 2007). The effects of music that remain even after the cessation of the stimulus are referred to as “residual effects”. Leon-Carrion et al. (2006) suggested that the effects of a sensory stimulus on an individual’s brain activity are even greater when the stimulus ceases. This serves to support the use of music as a pre-task strategy to evoke an optimal constellation of emotions and enhance physical performance.

Collectively, studies have shown that pre-task music can be used to regulate arousal, facilitate task-relevant imagery, enhance performance, and increase situational motivation in sport and physical activity contexts (e.g., Bishop et al., 2007; Bishop, Wright, & Karageorghis, 2014). Loizou and Karageorghis (2015) demonstrated that pre-task music can positively influence affective state in the preparation phase of an all-out physical task. Pre-task music also regulated the sympathovagal balance, which was examined via heart rate variability. Thus, pre-task music appears to regulate arousal and has the potential to engender an appropriate mental state for exercise. The scientist-practitioner can potentially use pre-task music as a means by which to promote greater work output during anaerobic-type activity (e.g., high-intensity interval training).

In-Task Music

Asynchronous or ambient music has been commonly used to make exercise or training feel more pleasant (Hutchinson & Karageorghis, 2013). Collectively, studies have indicated that in-task asynchronous music can reallocate an individual’s attentional focus to external stimuli, increase dissociative thoughts, and consequently ameliorate the effects of fatigue-related symptoms (e.g., Karageorghis & Jones, 2014). Jones et al. (2014) reported that even high-intensity exercise (e.g., 5% above ventilatory threshold) is more pleasant in the presence of music.

Researchers have also compared the effects of both asynchronous and synchronous music on psychophysiological variables during exercise. For example, Lim et al. (2014) demonstrated that affective responses during moderate-intensity exercise (90% of ventilatory threshold) were more positive for both asynchronous and synchronous music conditions compared to control. However, synchronous music influenced peripheral exertion (limbs) to a greater degree than asynchronous music.

Synchronous music has been used during exercise in order to reduce the variability that typifies human locomotion (Van Dyck et al., 2015). For example, exercisers and athletes can synchronize their movement patterns with the rhythmical qualities of music (Lim et al., 2014). Bacon, Myers, and Karageorghis (2012) demonstrated that participants who cycled for 12 min at 70% of the maximal heart rate under the influence of synchronous music consumed 7.2% less oxygen than when music tempo was not synchronized with the cyclic rotations. Accordingly, music can enhance the efficiency of movement leading to associated metabolic, cardiac, and pulmonary responses.

Post-Task Music

The application of post-task music is intended to expedite recovery after intense bouts of exercise, preventing injuries and cardiac complications. To date, only a limited number of studies have addressed the effects of post-task music (for review, see Karageorghis, 2017). The effects of post-task music are associated with the activity of the autonomic nervous system (ANS) on the sinoatrial node (Conrad et al., 2007). Accordingly, it appears that music can influence both sympathetic and parasympathetic activity.

Jing and Xudong (2008) used sedative music to accelerate the recovery of participants who exercised to the point of volitional exhaustion. Decreases in heart rate over time were greater in the music condition compared to control, which illustrates the potential application of slow, sedative music during passive recovery. Interestingly, music has also been used to facilitate active recovery. Eliakim, Bodner, Eliakim, Nemet, and Meckel (2012) used an up-tempo musical selection (140 bpm) to increase the number of steps and accelerate lactate removal rate following maximal treadmill exercise. Such findings indicate that listening to music after intense bouts of exercise can expedite physiological recovery (lactate clearance) and alleviate the effects of fatigue. Despite the still limited research on the effects of post-task music, the aforementioned studies indicate initial promise that music might aid the rate of recovery following moderate-to-high-intensity exercise or training.

Conclusions and Recommendations

A range of applications that pertain to embodied music interactions in the exercise and sport domain have been covered in this chapter. Such applications stem from relevant theoretical frameworks and putative underlying mechanisms. Research has shown that pre-task music can be used to manipulate emotional states, facilitate task-relevant imagery, and enhance subsequent motor performance. In-task music can boost work output, enhance affective state and reduce perceived exertion through both synchronous and asynchronous applications (e.g., Lim et al., 2014; Hutchinson et al., 2015). The efficacy of in-task music in regulating perceived exertion is moderated by physiological load such that music is relatively ineffectual in this regard beyond the ventilatory threshold. Nonetheless, when in-task music is selected with reference to its motivational qualities, it can temper the sharp decline in affect that is observed beyond the ventilatory threshold (cf. Ekkekakis, 2003; Hutchinson & Karageorghis, 2013; Jones et al., 2014). Research that addresses the application of post-task music is at a nascent stage, with initial findings showing considerable promise in terms of how music can be harnessed to expedite the recovery process that follows vigorous exercise or sports training (e.g., Eliakim et al., 2012).

Karageorghis's (2016) theoretical model (see Figure 1) provides a basis for issuing recommendations to practitioners who work with exercise and sport participants (e.g., fitness instructors, health professionals, coaches, physiotherapists). In line with this model, music selected as an accompaniment for exercise or sporting endeavors should be congruent with the participants' personal characteristics, the exercise task, the physical and social environment in which the activity takes place, and desired outcomes. With reference to contextual factors, the tempo of the music should be selected with exercise/training intensity in mind. Other than when warming up, warming down or recovering/recuperating, the appropriate band of tempi for the asynchronous application of music appears to be ~120–140 bpm (Karageorghis & Jones, 2014; Karageorghis et al., 2011). Furthermore, the rhythm of the music should approximate the motor patterns demanded by the activity (e.g., Leman et al., 2013).

This interaction of task-related and environmental factors should be considered with reference to training status—a personal factor—as highly trained exercisers/athletes will generally require less concurrent feedback/instruction in the execution of an exercise/training routine. The motor performance of highly trained participants is unlikely to be inhibited when relatively loud music is used (i.e., 75–80 dBA). Moreover, instructors engaged in one-on-one training are likely to maximize the efficacy of their instruction by restricting the use of their client's personal listening devices to periods of cardiovascular activity involving simple and repetitive motor tasks (e.g., cycle ergometry or treadmill walking), during which the exerciser or athlete may not require any verbal instruction.

Concerning the consequences of listening, music containing affirmations of exercise/sport or inspirational references to popular culture should be selected in order to promote task-relevant imagery and self-talk. Positive affect is thought to be consequent to the modality of music (e.g., major vs. minor key; Juslin, 2009) and its melodic/harmonic features in combination with lyrical content (e.g., Karageorghis, 2017). In order to stimulate participants, the music should be up-tempo (> 120 bpm) and characterized by pronounced rhythmical features. In order to sedate, a slow tempo (< 80 bpm), simple rhythmical structure, regular pulsation and repetitive tonal patterns based on a limited number of pitch levels are recommended (see e.g., Karageorghis, 2017). Practitioners and exercise/sport participants should routinely reflect upon and evaluate the consequences of their music-listening experiences and use this process as a means by which to inform future music selections. Such reflection is embodied in the feedback loop, from the consequences to the antecedents via the moderators, as illustrated in the theoretical model (Figure 1).

Through the circumspect application of the principles outlined in this chapter, practitioners with an interest in embodied music interaction will be able to harness the psychological, psychophysical, psychophysiological, and ergogenic effects of music with greater precision. In terms of future scientific investigation, it is envisaged that neurophysiological approaches will play an increasingly important role in the development of this area of study (cf. Bishop et al., 2014). This research channel will be facilitated by continued advances in and widespread application of functional neuroimaging and near-infrared spectroscopy technologies.

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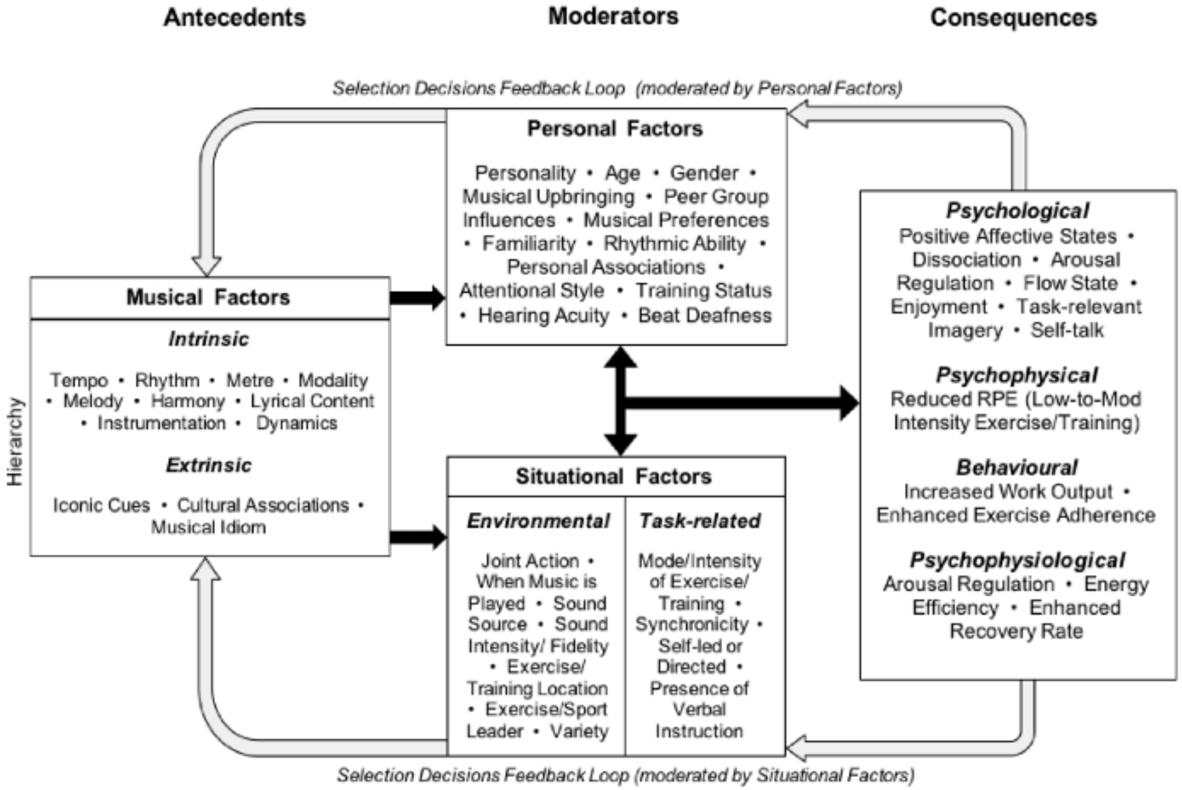

Figure 1. A theoretical model of the antecedents, moderators, and consequences of music use in the exercise and sport domain.

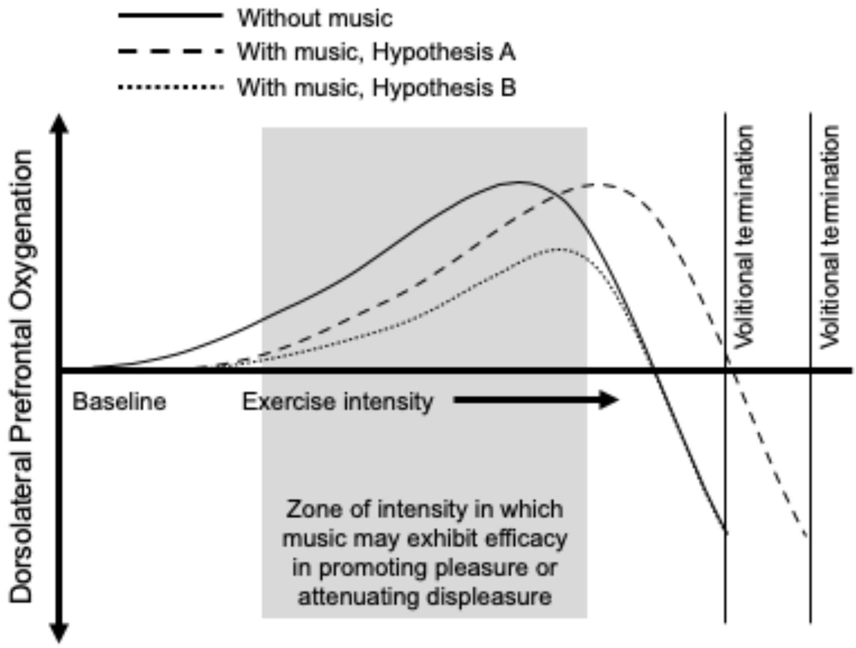

Figure 2. Hypothetical changes in the oxygenation (i.e., activation) of the dorsolateral prefrontal cortex across increasing levels of exercise intensity (see Putative Brain Mechanisms for explanation).