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Cerebral effects of music during isometric exercise: An *f*MRI study☆

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ABSTRACT

A block-design experiment was conducted using *f*MRI to examine the brain regions that activate during the execution of an isometric handgrip exercise performed at light-to-moderate-intensity in the presence of music. Nineteen healthy adults (7 women and 12 men; $M_{age} = 24.2$, $SD = 4.9$ years) were exposed to an experimental condition (music [MU]) and a no-music control condition (CO) in a randomized order within a single session. Each condition lasted for 10 min and participants were required to execute 30 exercise trials (i.e., 1 trial = 10 s exercise + 10 s rest). Attention allocation, exertional responses, and affective changes were assessed immediately after each condition. The BOLD response was compared between conditions to identify the combined effects of music and exercise on neural activity. The findings indicate that music reallocated attention toward task-unrelated thoughts ($d = 0.52$) and upregulated affective arousal ($d = 0.72$) to a greater degree when compared to a no-music condition. The activity of the left inferior frontal gyrus (lIFG) also increased when participants executed the motor task in the presence of music ($F = 24.65$), and a significant negative correlation was identified between lIFG activity and perceived exertion for MU (limb discomfort: $r = -0.54$; overall exertion: $r = -0.62$). The authors hypothesize that the lIFG activates in response to motor tasks that are executed in the presence of environmental sensory stimuli. Activation of this region might also moderate processing of interoceptive signals – a neurophysiological mechanism responsible for reducing exercise consciousness and ameliorating fatigue-related symptoms.

1. Introduction

Environmental sensory stimuli such as music have been used extensively in exercise- and sport-related tasks (e.g., Terry et al., 2012). They are a means by which to assuage fatigue-related symptoms, elicit more positive affective responses, up/downregulate affective arousal, and enhance the neural control of working muscles (Bigliassi et al., 2017; Hutchinson et al., 2018). Music has also been considered a sensory distraction with the potential to increase adherence to physical activity and counteract the detrimental effects of sedentariness (Clark et al., 2016). Interestingly, the brain mechanisms that underlie the effects of music on exercise have only recently been investigated (e.g., Bigliassi et al., 2016; Tabei et al., 2017). Ascertaining the key networks that activate in response to music will facilitate further understanding of complex phenomena such as selective attention and the perception of fatigue.

1.1. Psychophysiological mechanisms

The combined effects of peripheral feedback associated with interoceptive cues (e.g., group III and IV muscle afferents) are hypothesized to elicit the conscious perception of fatigue (Pollak et al., 2014; St Clair Gibson et al., 2003). An increase in exercise intensity draws the exerciser's attentional focus toward bodily sensations, thereby eliciting greater awareness of fatigue-related symptoms (e.g., limb discomfort). Conversely, exposure to environmental sensory cues (e.g., music or video images) can guide attentional focus toward task-irrelevant cues during exercise (Karageorghis and Jones, 2014). Therefore, exercise-related signals are hypothesized to be in constant competition for attention with external influences (Rejeski, 1985). It should be noted that attentional focus is usually allocated to both internal and external sensory cues in tandem. Nonetheless, the degree to which attention is directed toward interoceptive or exteroceptive signals is primarily defined by the stimulus relevance (Broadbent, 1958; Tenenbaum, 2001).

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Music-related interventions have the potential to increase the frequency of dissociative thoughts, moderate the salience of fatigue-related cues, and make exercise feel more pleasant than under no-music control conditions (e.g., Hutchinson and Karageorghis, 2013; Lim et al., 2014). Ameliorated fatigue enables exercisers to experience several positive outcomes, such as enhanced affective valence and situational motivation (Hutchinson and Karageorghis, 2013). Stimulative pieces of music might also modulate cardiac, respiratory, and muscular activities via neurohumoral pathways, as advanced by Conrad et al. (2007). According to these authors, music may up/downregulate physiological arousal with consequent impact upon the activity of the autonomic system.

Psychophysiological responses elicited by music during the execution of movements are primarily moderated by interoceptive signals (Boutcher and Trenske, 1990; Karageorghis et al., 2017). As the organ responsible for processing and generating signals, the human brain facilitates the interpretation of interoceptive cues and controls bodily functions (Chiel et al., 2009). Attentional reallocation induced by auditory and motor signals is accordingly controlled by the brain (Zatorre et al., 2007). Therefore, the human brain will, presumably, hold the answer in terms of furthering understanding of the mechanisms that underlie the multifarious effects of music during exercise-related tasks.

Bigliassi et al. (2016) recently conducted an experiment employing electroencephalography (EEG) to investigate the cerebral and psychophysiological mechanisms that underlie the effects of music during an isolated limb exercise. The results indicated that music promoted the use of dissociative thoughts and enhanced task performance during the execution of a highly fatiguing isometric ankle-dorsiflexion task. The brain mechanisms associated with this response appeared to be associated with the down-modulation of low-frequency components (mainly theta waves) of the power spectrum at the frontal, central, and parietal electrode sites. The authors hypothesized that low-frequency components of the EEG waveform are upregulated by processing of interoceptive signals (Craig et al., 2012; Pires et al., 2018). As music redirects attention toward task-irrelevant cues, the detrimental effects of fatigue are partially suppressed. Thus, the central motor command (i.e., precentral and paracentral gyri; Voss et al., 2006) is able to maintain the efferent control of working muscles for a longer period of time (de Morree et al., 2014).

1.2. Effects of exercise and music on brain activity

Brain assessment techniques are frequently used in the field of cognitive psychology and behavioral medicine as a means by which to explore the neurophysiological mechanisms that underlie the effects of music on attentional and emotional responses (Bigliass et al., 2018a; Juslin, 2013). The manifold effects of music on brain activity include increased activation in the temporal lobe, insular cortex, limbic system, and frontal regions of the brain (see Koelsch, 2011; Warren, 2008). This is primarily attributed to the fact that each brain region is concerned with the processing of specific components of music (e.g., melody and harmony) and/or subsequent emotional responses that are elicited by music (Levitin, 2008).

Interestingly, the execution of movement prompts increased activation in brain regions that are also affected by music (Enders et al., 2016; Fontes et al., 2015; van Praag, 2009). For example, Schneider et al. (2010) examined brain function using EEG before and after an exhaustive running task. The results of this study indicated that an incremental treadmill test increased the activity of the left frontal regions of the brain. The researchers postulated that such an increase in brain activity was, perhaps, associated with emotional processing. This hypothesis was based on the long-held view that left-hemisphere brain regions are associated with positive emotions such as happiness and joy (Demaree et al., 2005), while the right-hemisphere regions are associated with negative affect. Along similar lines, the right dorsolateral prefrontal cortex has also been hypothesized to play an important role in the modulation of pain (Dunckley et al., 2007). Accordingly, this region could be germane to the perception of muscular fatigue during exercise (Karageorghis et al., 2017).

It should be emphasized that *f*MRI experiments have seldom been investigated during the execution of physical tasks. This is because limb movements cause artefacts that are challenging to remove using traditional cleaning procedures (Maclaren et al., 2013; Oakes et al., 2005). Furthermore, MRI scanners generate a strong magnetic field, meaning that only compatible nonmagnetic devices can be used in the scanning room to measure participants' movements (e.g., force produced; Thickbroom et al., 1998).

1.3. Aim of the present study

Very few studies have examined the effects of music and isolated limb exercises using an MRI scanner to ascertain the neurophysiological mechanisms that underlie commonly observed phenomena such as attentional dissociation and variations in core affect (cf. Bishop et al., 2014; Brown et al., 2006). Accordingly, a block-design experiment was conducted using *f*MRI in order to examine the neural networks that activate during the execution of handgrip tasks performed at light-to-moderate intensities in the presence of ambient music.

1.4. Research hypotheses

We hypothesized that the presence of music would guide attentional focus externally, thus partially preventing afferent signals from entering focal awareness. The upshot would be the amelioration of fatigue-related sensations (e.g., limb discomfort), upregulation of affective arousal, and elicitation of a more positive affective state (Karageorghis, 2017). We also hypothesized that attentional shifts induced by the presence of music would influence the neural control of working muscles (i.e., decreasing the activity of the precentral gyrus; Bigliassi et al., 2017). Bigliassi et al. (2017) identified that music-related interventions have the potential to rearrange the electrical frequency of the central motor command and reduce communication across somatosensory regions of the cortex. Moreover, they demonstrated that music suppressed the resynchronization of the neural population beneath the Cz electrode site (i.e., central area of the precentral gyrus). The authors suggested that music can reallocate attention externally and induce more autonomous control of the working muscles. Therefore, it appears reasonable to surmise that the activity of the left precentral gyrus would decrease when participants exercise in the presence of music.

It has also been hypothesized that the activity of the right dorsolateral prefrontal cortex would decrease when participants exercise in the presence of music (see Karageorghis et al., 2017). This reduction could cause a delay in the eventual decline in prefrontal oxygenation and thus prolong exercise performance. Karageorghis et al. (2017) also suggested that there could be a smaller increase in oxygenation at moderate exercise intensities; presumably due to the lower level of experienced displeasure, thus reducing the need for a participant to cognitively control the displeasure, even in the absence of any ergogenic effect. With this premise, we hypothesize that a decrease in activation of the right dorsolateral prefrontal cortex will manifest when participants exercise with music.

2. Method

2.1. Participants

The required sample size was calculated using G*Power 3.1 (Faul et al., 2007) for an *F* test (within-factors, repeated-measures ANOVA). The effects of stimulative music on attentional focus during isometric exercise performed to the point of volitional exhaustion were used as group parameters to estimate the effect size required to calculate the necessary sample size. The study by Bigliassi et al. (2016) was used to