THE EFFECT OF HIGH TEMPO MUSIC AS AN EXTERNAL STIMULUS DURING HIGH INTENSITY EXERCISE

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THE EFFECT OF HIGH TEMPO MUSIC AS AN EXTERNAL STIMULUS DURING HIGH INTENSITY EXERCISE

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LIST OF ABBREVIATIONS

ANOVA – Analysis of Variance

BF – Breathing Frequency

bpm – Beats per Minute

cm - Centimeter

CNS – Central Nervous System

CO2 – Carbon Dioxide

fMRI - Functional magnetic resonance imaging

HR – Heart Rate

mm – Millimeter

MVC – Maximal Voluntary Contraction

O2 – Oxygen

PPO – Peak Power Output

RBL – Resting Blood Lactate

RBP – Resting Blood Pressure

RHR – Resting Heart Rate

RPE – Rate of Perceived Exertion

RPM – Revolutions per Minute (Pedaling Rate)

s - Seconds

SD – Standard Deviation

SE – Standard Error

TTF – Time to Task Failure

VCO2 – Carbon Dioxide Output

V_E – Minute Ventilation

VO2 – Oxygen Uptake

VO_2 Max – Maximal Oxygen Consumption

V_T – Tidal Volume

μL – Microliter

CHAPTER 1: INTRODUCTION

"Without music, life would be a mistake."

– Friedrich Nietzsche (1888)

Background of Study

Music is an art form whose medium is sound. It has common elements such as pitch (melody and harmony), and rhythm and tempo. In the technology age in which we currently live, it is not uncommon to walk around a workout facility and see an individual with a portable music device of some kind attached to their body or their clothing, usually wearing headphones making them oblivious to the rest of the world. As music use during exercise becomes more popular, so to do the number of questions about why people choose to exercise with music. How does music influence an individual psychologically or physiologically when working out?

Based on previous research, music has been shown to be both facilitating and distracting towards human performance (Dalton & Behm, 2007). Some believe music allows a separation of thought from feelings, altering perception, similar to the cognitive strategy of dissociation (Atkinson, Wilson, & Eubank 2004; Edworthy & Haring 2006). Others believe music can act as either a stimulant or a sedative prior to and during physical activity (Yamashita, Iwai, Akimoto, Sugawara, & Kono, 2006; Murrock & Higgins 2009). Finally, others theorize that there is synchronization between the music's tempo and human movements making exercise a more harmonious or less stressful experience (Rendi, Szabo, & Szaba, 2008; Waterhouse, Hudson, P & Edwards, 2009). Currently there is an agreement among previous studies that listening to music while performing sub-maximal exercise results in a decreased rating of perceived exertion (Atkinson et al. 2004; Bharani, Sahu, & Mathew 2003; Edworthy & Waring 2006; Karageorghis, Mouzourides, Priest, Sasso, Morrish, & Whalley, 2009; Yamashita et al. 2006). However what has not been conclusively shown is whether listening to music has an effect on the body's physiological responses to exercise, specifically with respect to high intensity or maximal work efforts.

A study conducted by Szmedra & Bacharach (1998) looked at physiological measures of exercise induced fatigue rather than the purely psychological measures. They examined plasma lactate, norepinephrine and cardiovascular hemodynamics in ten well trained men during treadmill running in two conditions: one while listening to music and one without. They were among the first to suggest that music may have a 'psychobiological' impact on an exercise participant; they noted higher values for hemodynamics and blood lactate in the no music trials suggesting a greater metabolic demand while oxygen consumption was unchanged. However, since this study there has not been an overwhelming amount of follow-up work on the physiological effects of music on exercise performance and the small amount of literature that is available contains several inconsistencies and a lack of conclusive evidence. Thus it is important to try and move forward with this research in an effort to further our understanding of the possible benefits of using music during exercise and address the potential to increase exercise performance, enjoyment and adherence for a wide range of exercise participants, possibly including the untrained, athletic and clinical populations.

Purpose of Study

Exercise induces a number of psychological and physiological responses including but not limited to an increase in perceived exertion, heart rate, breathing frequency and amount of blood lactate. The purpose of the current thesis is to determine whether listening to high tempo music (130 bpm) while performing high intensity bouts of cycling can improve a participant's time to task failure (TTF) and have a positive effect on the commonly seen physiological signs of fatigue; the results will expectantly allow us to extrapolate some more potential uses of music in the exercise setting and possible limitations.

The literature suggests that music has both measurable and consistent effects on behaviour and psychological states of exercise participants (Karageorghis, Terry, Lane, 1999; Lucaccini & Kreit, 1972; Terry & Karageorghis, 2011). Also, during repetitive endurance-type activities 'motivational' music can decrease rates of perceived exertion and can even lead to increased work load (Atkinson et al., 2004; Edworthy & Haring, 2006; Murrock & Higgins, 2009, Terry & Karageorghis, 2011; Yamashita et al., 2006). However, the actual mechanisms underlying the beneficial effects music has on exercise performance are still elusive. Thus, future research is necessary to develop a better understanding of the effect of listening to music while exercising.

Significance of Study

At least 60% of the world's population does not get sufficient exercise, according to the World Health Organization (WHO, 2009). Thus, it is important to try and promote increased physical activity and exercise in daily living. One of the most pervasive findings in the many studies done with music and exercise is that the participant finds the exercise more enjoyable (Atkinson et al., 2004; Edworthy & Haring, 2006; Murrock & Higgins, 2009, Terry & Karageorghis, 2011; Yamashita et al., 2006). If we are able to further support this idea and expand our knowledge about the types and levels of exercise that can be positively influence by the use of music we can further help the general public to make exercise more enjoyable and hopefully increase lifelong exercise adherence.

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CHAPTER 2: LITERATURE REVIEW

A REVIEW OF RECENT LITERATURE ON THE EFFECTS OF USING MUSIC DURING EXERCISE PERFORMANCE

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Abstract

In society today music use by athletes and exercise enthusiasts alike has become extremely popular, however the music selection process is typically quite personal and based often on intuition rather than any type of scientific formula. Some people say a certain type of music motivates them, some people suggest it is a certain beat or tempo and some people say it is any type of music at all. One thing that is commonly agreed upon however is that for whatever reason the music seems to make exercising more enjoyable. Thus, the present review of literature on music use during exercise is to develop an understanding of the scientific evidence as a basis for the finds that music can assist in exercise performance. The proposed benefits of using music in the exercise setting have intrigued researchers for quite some time even before portable music devices were easily accessible to the general public. There is a whole body of literature that suggests that during repetitive endurance-type activities 'motivational' music can decrease rates of perceived exertion and can lead to a positive impact on exercise performance measures. However, what has not been conclusively shown is whether listening to music has a purely psychological effect, a physiological effect, or a psychophysical effect on the participant and their responses to exercise. The actual mechanisms that are responsible for the beneficial effects music can have on exercise performance are still equivocal. Thus, future research is necessary to develop a better understanding of the effect and effect limitations of listening to music for improved exercise performance.

Introduction

Music is an art form whose medium is sound, composed of many elements including pitch, tempo, melody, duration, and volume. However, it is not a simple all-encompassing term. All of the elements can be varied, creating an unlimited number of potential compositions that can be called music. Nonetheless, all types and forms of music have long been thought to affect the senses and the mind. For example, many people talk about feeling the music, experiencing the music or in some cases even seeing the music (Hargreaves & North, 2008). The idea that music influences the senses and the mind has interested researchers for quite some time and was brought to the forefront of applied exercise science research for many reasons; one being to investigate the potential uses of music for increased improvements in exercise performance which may be able to promote public health by increasing the willingness to participate in physical activity on a daily basis.

The effects of music in exercise settings, sports arenas and other physical activity contexts has been investigated over the years; also including but not limited to the effects of music use during rehabilitation, physical therapy and occupational therapy (Atkinson, Wilson, & Eubank 2004; Boutcher & Trenske, 1990; Copeland & Franks, 1991; Edworthy & Haring, 2006; Karageorghis, Terry, Lane, 1999; Lucaccini & Kreit, 1972; Murrock & Higgins, 2009; Terry & Karageorghis, 1997; Terry & Karageorghis, 2011, Uppal & Datta, 1990). There is an agreement among current experts in the field that most of the research conducted prior to the mid-1990s addressing the benefits of music in an exercise setting produced only equivocal findings (Karageorhis & Terry, 1997). It is suggested that methodological limitations play a major role in the lack of consistency or variable quality in the findings. Mainly, the methodological limitations surround the use of music terminology, music selection, failure to specify music intensity (volume) and the inappropriate selection of dependent variables due to confounding variables.

Over the past decade more studies have been conducted in an effort to overcome the earlier methodological challenges, to test the aforementioned former hypotheses with greater precision and to create and test new hypotheses. These studies make up the bulk of the literature which will be discussed in this review. According to this current literature music can: capture attention, trigger a range of emotional responses, alter mood, evoke memories, increase work output, increase arousal, reduce inhibitions and encourage rhythmic movement (Anshel & Marisi, 1978; Karageorghis, Terry, Lane, 1999; Lucaccini & Kreit, 1972; Terry & Karageorghis, 1997; Terry & Karageorghis, 2011). In reference to the exercise setting, these findings translate to this external stimulus (music) being able to improve exercise performance, reduce perceptions of fatigue and increase individual work capacity. The long term benefits of music use are still under investigated but potentially include increased adherence to exercise programs as a result of lower perceived exertion and increased positive performance due to greater work capacity (Atkinson et al., 2004; Edworthy & Haring, 2006; Murrock & Higgins, 2009, Terry & Karageorghis, 2011; Yamashita et al., 2006).

The purpose of this literature review is to critically evaluate and synthesise the current research on the effects of music in an exercise context, with the aim of identifying future directions for research. A small portion of the review will also look at a popular debate in exercise science, whether the causes of exercise induced fatigue are peripheral and metabolite induced or central stemming from somewhere in the central nervous system. The incorporation of this small subsection is in an effort to better understand the possible mechanisms involved in the consistent and measureable effects music has on exercise participants.

Music and Exercise

A. *The early studies*

A select number of studies conducted before the mid-1990s demonstrated that music can have significant 'psychophysical' benefits during physical activity (Boutcher & Trenske, 1990; Copeland & Franks, 1991; Lee, 1989). These studies demonstrated exercise performance improvements in terms of improved motor performance and increased aerobic endurance, and also showed enhanced 'exercise experience' by using music as an external stimulus. The proposed mechanisms through which music produced these psychophysical benefits included lowered perceived effort, arousal control, improved affective states, and a possible movement synchronization effect. In contrast, other studies conducted with similar tasks and procedures during this time period were unable to produce any psychophysical benefits, which resulted in conflicting inferences (Patton, 1991; Pujol & Langenfeld, 1999; Schwartz, Fernhall, & Plowman, 1990).

The main objective of this area of research prior to the mid-1990s was to measure the interaction of music and exercise on a psychophysiological level. The most common dependent variables used were, heart rate (HR), as the physiological measure, or Borg's (1970, 1982) RPE scale, as the psychophysical measure. Copeland and Franks (1991) examined the effects of "soft/slow" and "loud/upbeat" asynchronous music on treadmill endurance. HR was measured every 30 seconds until voluntary exhaustion was reached. They reported that HR was significantly ($p<0.01$) higher in the "loud/upbeat" music group compared to the HR in the "soft/slow" music group. The authors suggested that these results provided support for the hypothesis that soft/slow music reduces physiological arousal during submaximal exercise, thereby increasing endurance performance. In contrast, other studies around this time period failed to show any influence of music on HR. Lee (1989) investigated HR during submaximal treadmill running between Baroque music (60 bpm), an upbeat rock selection (152 bpm), and a non-auditory control condition and found no significant differences. Similarly, Schwartz et al. (1990) reported that during cycle ergometry at 75% VO_2 max, untrained subjects showed no significant differences in HR, or in oxygen uptake, minute ventilation, respiratory quotient and blood lactate between simulative music and a control condition. These conflicting findings are now suggested to be the result of methodological limitations of the time period discussed earlier including but not limited to improper use of music terminology, poor music selection, failure to specify music intensity (volume) and the inappropriate selection of dependent variables resulting in confounding variables. The juxtaposing nature of the results continues when you look at the other commonly used measure of RPE. The only consistent finding during this time was that music appeared to be more effective in reducing perceived exertion during submaximal exercise than beyond anaerobic threshold (Boutcher & Trenske, 1990; Copeland & Franks, 1991; Johnson & Siegel, 1987; Schwartz et al., 1990). The intensity of exercise appeared to modulate the relationship between attentional processes and psychophysical effects. High intensity exercise was suggested to result in attentional switching from external stimuli, such as music, to internal stimuli, such as sensations of fatigue. Rejeski (1985) explained how psychological and physiological factors combine to influence ratings of perceived exertion through a parallel information processing model. He proposed that sensory and affective information is processed pre-consciously in parallel. Thus, sensory information such as a sense of effort, or affective information, such as apprehension resulting from a heavy work load, can form the object of attention and determine affective responses and RPE during exercise. In some of the current literature his conceptual framework is still proposed as a possible mechanism for the effects of music on exercise enjoyment and performance (Karageorghis & Priest, 2012a; Karageorghis & Priest, 2012b).

Several other studies looked specifically at the synchronization of movement with music and consistently showed an ergogenic effect (Anshel & Marisi, 1978; Michel & Wanner, 1973; Uppal & Datta, 1990). However, a number of studies which examined the effects of asynchronous (background) music produced equivocal findings. Some report psychophysical effects (Boutcher & Trenske, 1990; Copeland & Franks, 1991), whereas other studies showed no effects (Pujol & Langenfeld, 1999; Schwartz, Fernhall, & Plowman, 1990). One of the major limitations was the general failure to control for musical selection criteria used and to report procedures in sufficient detail. Researchers often failed to specify what tempo the music was, and at what volume the music was played, making it difficult for the reader to evaluate the results. Failure to specify music intensity (volume) further complicates the interpretation of findings as previous studies have suggested that louder volumes seem to require greater cognitive processing within the central nervous system (CNS) (Dalton, Behm & Kibele, 2007). As the exact mechanisms involved are yet to be determined, this is an important variable to consider. The only definitive conclusions that could be drawn from the early studies are that a multitude of factors seem to influence reactions to music making a valid and reliable scientific investigation a difficult task, but nevertheless, additional research into the potential benefits of music use during exercise performance was warranted. It appears likely even from these studies that appropriately selected musical accompaniment to exercise and sport-related activities can enhance the enjoyment, performance measures and potentially adherence levels of participants (Karageorghis & Terry, 1997).

B. The role played by music type and tempo

Music tempo has an important influence on the responsiveness to music in exercise and sport settings (see Table 1 for summary). The term 'motivational' music has become popularized and usually refers to music with a high tempo band width of between 125-140 bpm (Karageorghis & Priest, 2012a; Karageorghis & Priest, 2012b). However, the term is still loosely defined and research results still vary. Barwood et al. (2004) demonstrated that 'motivational' music had no significant effect on the participants' heart rate or RPE during treadmill exercise, whereas a study with an almost identical protocol found statistically significant changes in both heart rate and RPE as a result of using this 'motivational' music (Szmedra & Bacharach 1998). Thus the question becomes, what elements of this music actually elicited the response? Was it the influence of a covariate or more importantly how exactly are they classifying motivational music? This idea of arbitrarily selecting music without full consideration of the elements (Simpson & Karageorghis, 2006) called to attention the need for a standardized-theory-based-method of selecting music. In the research to date there have been two attempts at creating such a method: 1) the Brunel Music Rating Inventory (BMRI; Karageorghis et al., 1999) and 2) the BMRI-2 (Simpson & Karageorghis, 2006). However, both of these methods list the characteristics of 'motivational' music as simply fast tempo, strong rhythm, energy enhancing, and able to promote bodily movement. Thus, there is some ambiguity and subjectivity still present and room for improvement in the creation of a more centralized theory based method to make all studies more comparable and universal. Without this tool, music selection will continue to be a large threat to the external validity of research studies in this area. Fortunately over the last decade a body of research has started to develop which focuses on identifying factors that contribute to the motivational qualities of music, qualities that elicit the greatest positive effects on performance and inspire the listener to exercise harder and/or for longer (Crust & Clough, 2006; Karageorghis et al., 2009; Karageorghis et al., 2010; Karageorghis, Jones, Priest, Akers, Clarke, Perry et al., 2011; Karageorghis & Priest, 2012A; Karageorghis & Priest, 2012B; Terry & Karageorghis, 2011).

Originally in the majority of studies published the specific type and tempo of the music selection was underappreciated as a possible confounding variable. Following more careful attention given to this idea over the last couple years however specific musical qualities, such as tempo, have been better classified with regards to which music selections and characteristics are able to stimulate or inspire positive effects on physical activity. There has even been a recent increase in studies that have investigated more closely at the links between exercise heart rate, exercise intensity and preferred music tempo (Karageoroghis, Jones et al., 2006; Karageorghis, Jones & Stuart, 2008; Karageoghis et al., 2011). The results of these studies have supported real world observations that faster or higher tempo music is the preferred and most beneficial type of music used to stimulate improvements in exercise performance.

In a study by Iwanaga (1995) an arousal hypothesis was purposed, on the basis that an exercise heart rate to music tempo preference could possibly be a linear relationship; conversely when plotted on a graph the relationship clearly exhibited non-linear features and the relationship is now thought to be more complex. A notable finding in the aforementioned study nevertheless was that exercisers did exhibit a very narrow tempo band preference of 125-140 bpm when exercising. This band width is classified in musical Latin terminology as *Allegro* which means fast, quickly and bright. It has since been suggested by several other authors that this band width, 125-140 bpm, is the most beneficial to promote positive influences on performance by improving endurance and/or exercise intensity for most healthy exercisers engaged in repetitive, aerobic-type activities (Crust & Clough, 2006; Karageorghis, Jones, Priest, Akers, Clarke, Perry et al., 2011; Karageorghis et al., 2009; Terry & Karageorghis, 2011). It is also advantageous for the rhythm of the music to approximate movement patterns entailed where possible (Crust, 2008; Schneider et al., 2010). Future research endeavors should capitalize on the pre-determined appropriate band of tempi which is congruent in the current literature to explore further the psychological, physiological and psychophysical effects of music on exercise performance. This will hopefully help to eliminate confounding variables that have previously resulted from not controlling for music selection elements. Differential reactions to music and the influence of other selected musical characteristics such as volume, and lyrics can also be explored with this valuable knowledge about tempo.

Table 1. Summary of the current literature on the role played by music type and tempo

Author(s) YEAR	Purpose	Sample	Variables	Results
L.Szmedra & D.W. Bacharach (1998)	To examine the effects of listening to headphone music during treadmill running	10 well trained men (25.1 ± 6 years)	**Dependent:** - Rate of Perceived Exertion (RPE) - Plasma Lactate (LA) - Norepinephrine (NE) - Cardiovascular Hemodynamics - Heart Rate (HR) - Systolic Blood Pressure (SBP) - Rate-pressure product **Independent:** - Treadmill Running with Music (M) - Treadmill Running without Music (NM)	**HR:** $p < .05$ between NM and M; 152.9±5.3 to 145.9±4.7 bpm **SBP:** $p < .05$ between NM and M; 158.1±3.7 to 151.7±3.3 mmHg **RPP:** $p < .05$ between NM and M; 242.2±11.5 to 222.1±11.4 **LA:** $p < .05$ between NM and M; 2.75±0.15 to 2.13±0.18 mmol / L **RPE:** $p < .05$ between NM and M; 14.4±0.4 to 12.9±0.4 **NE:** $p > .05$ between NM and M; 841.5±314.7 to 694.1±254.5 pg / mL
T. Pujol & M. Langenfeld 1999	To assess whether music affects performance on the Wingate (Supra-maximal) Anaerobic Test.	N = 15, 12 men and 3 women	**Dependent:** - Mean Power Output (MPO) - Maximum Power Output (MaPO) - Minimum Power Output (MiPO) - Fatigue Index (FI) - Time to Fatigue (TTF) **Independent:** - Wingate with Music (M) - Wingate without Music (NM)	No statistical differences

S. Simpson & C. Karageorghis (2006)	To assess the effects of motivating and oudeterous (neither motivating nor demotivating) synchronous music on 400m sprint performance.	Twenty Caucasian Males (age mean = 20.5±1.2) rated motivational qualities of the music; Thirty-Six Caucasian Males (age mean = 20.4±1.4) comprised the experimental group	**Dependent:** - Brunel University Mood Scale (BUMS) - Time to completion of a 400m sprint (TC) **Independent:** - No music control (c) - Motivational music (a) - Oudeterous music (b)	**(a):** Mean TC = 72.27 ± 1.39s **(b):** Mean TC = 72.64 ± 1.20s **(c):** Mean TC = 72.95 ± 1.24s Significant effect ($F_{1.24, 42.19} = 10.54$, $p < .001$) between the music and control conditions but no significant difference between motivational and oudeterous.
S. Yamashita, K.Iwai, T. Akimoto, J. Sugawara & I. Kono (2006)	To investigate the relationship between the influence of music on RPE during sub-maximal exercise and on the autonomic nervous system before and after sub-maximal exercise.	Eight healthy adult males (age mean = 21±0.9).	**Dependent:** - Rate of Perceived Exertion (RPE) - Heart Rate (HR) - Influence on Autonomic Activity (IAA) **Independent:** - Exercise at 40% of VO_2 Max with music - Exercise at 40% of VO_2 Max without music - Exercise at 60% of VO_2 Max with music - Exercise at 60% of VO_2 Max with music	**RPE:** $p < .05$ between Non-Music and Music conditions; for 40% VO_2 Max but not for 60% VO_2 Max **HR:** No significant findings **IAA:** No significant findings as a result of music
J. Edworthy & H. Waring (2006)	To examine the effects of loudness and tempo of background music on exercise performance.	Thirty volunteers (N = 15 females and N = 15 males) between the ages of 18 and 63 years.	**Dependent:** - Rate of Perceived Exertion (RPE) - Heart Rate (HR) - Feeling Scale (FS) **Independent:** - Fast Music (FM) - Loud Music (LM) - Quiet Music (QM) - Slow Music (SM) - No Music (NM)	**HR:** Significant main effect of tempo ($F_{1,29}$=7.27, p <0.05). Significant main effect of time ($F_{2,29}$=700.1, p <0.001). **RPE:** Significant main effect of tempo ($F_{1,29}$=35.32, p <0.001). **FS:** Significant main effect of time ($F_{1,29}$=19.94, p <0.001).
M.J. Barwood, N.J.V. Weston, R. Thelwell & J. Page (2004)	To examine the beneficial effect that a motivational music and video intervention could have on high intensity exercise performance under moderate environmental stress.	Six healthy male participants (age mean = 20±1 years).	**Dependent:** - Distance Covered (DC) - Heart Rate (HR) - Blood Lactate (BL) - Rate of Perceived Exertion (RPE) **Independent:** - Control (CON) - Motivational Music and Video (M) - Non-motivational (NM)	**DC:** Significantly greater distance covered in the M condition when compared to the NM ($F_{2,10}$= 11.29, p < 0.05) **BL:** Significantly greater accumulation in the M compared to the NM (p = 0.05) **HR:** No significant differences **RPE:** No significant differences
A. Bharani, A. Sahu & V. Mathew (2003)	To examine the effect of passive distraction on treadmill exercise test performance	Twenty healthy males (age mean = 26.9±2.8years)	**Dependent:** - Time to Exhaustion (TTE) - Heart Rate (HR) - Pressure-Rate Products (PRP) - Rate of Perceived Exertion (RPE) **Independent:** - Music Condition (MC) - Non-Music Condition (NMC)	**HR:** Participants in the MC were able to achieve higher peak heart rates (p < 0.05) **RPE:** Participants in the MC showed lower ratings (p < 0.0005) **TTE:** Participants in the MC were able to exercise longer (p < 0.0005)
A. Szabo, A. Small & M. Leigh (2009)	To investigate, based on the parallel information processing model and arousal hypothesis, whether musical tempo and its manipulation during exercise affect the maximal workload achieved during progressive cycling.	Twenty-four volunteers (N = 12 male, N = 12 female; age mean = 20.8±0.64 years)	**Dependent:** - Workload (WL) - Heart Rate (HR) - Time to Exhaustion (TTE) **Independent:** - Control (C) - Slow Music (SM) - Fast Music (FM) - Fast to Slow Music (FSM)	**WL:** Significantly higher in the FSM condition (p<0.05). **HR:** No significant differences

M. Rendi, A. Szabo & T. Szabo (2008)	To investigate the impact of fast- and slow-tempo music on 500-m rowing sprint performances.	Twenty-two regularly training rowers (age mean = 28.5±8.7 years)	**Dependent:** - Strokes per minute (SPM) - Time to Completion (TTC) - Rated Perceived Exhaustion (RPE) **Independent:** - Without Music (WM) - Slow Music (SM) - Fast Music (FM)	**TTC:** Significant differences ($F_{1.3,26.5}$= 8.3, $p < 0.005$) between conditions with the FM condition being the fastest. **SPM:** Significantly greater in the FM condition ($F_{1.7,34.4}$= 19.34, $p < 0.001$) **RPE:** No significant difference
L. Birnbaum, B. Huschle & T. Boone (2009)	To study the effects of fast and slow music on cardiovascular and hemodynamic responses during submaximal treadmill exercise	Eleven healthy college-aged students (N = 6 males and N = 5 females)	**Dependent:** - Oxygen Consumption (VO_2) - Ventilation (Ve) - Heart Rate (HR) - Blood Pressure (BP) - Cardiac Output (CO) **Independent:** - Without Music (WM) - Slow Music (SM) - Fast Music (FM)	**VO_2:** Significantly higher ($p < 0.05$) in the FM condition **HR and BP:** No significant differences
T. Yamamoto, t. Ohkuwa, H. Itoh, M. Kitoh, J. Terasawa, T. Tsuda, S. Kitagawa & Y. Sato (2003)	To examine the effect of listening to two different types of music (with slow and fast rhythm), prior to doing super-maximal cycle exercises, on performance, heart rate, the concentration of lactate and ammonia in blood and the concentration of catecholamine's.	Six male students (age mean = 24±4.1 years)	**Dependent:** - Rate of Perceived Exertion (RPE) - Mean Power Output (MPO) - Plasma Norepinephrine (NE) - Blood Lactate (BL) - Plasma Catecholamine (PC) **Independent:** - Slow Rhythm Music (SR) - Fast Rhythm Music (FR)	**MPO, BL & PC:** No significant differences **NE:** Significant decreases while listening to SR and significant increases while listening to FR
J. Waterhouse, P. Hudson & B. Edwards (2009)	To investigate the effects of the duration and tempo of separate tracks, as well as of the overall program of music, upon physical activity and subjective responses to exercise of low-to-moderate intensity.	Twelve healthy male University students (age mean = 21.3±3.1 years)	**Dependent:** - Heart Rate (HR) - Distance/Unit Time (Dt) - Total Work (TW) - Power (P) **Independent:** - Slow Tempo (ST) - Fast Tempo (FT)	No statistical differences

C. The effect or effect limitations of exercise intensity

In low-to-moderate intensity endurance tasks, strong support has been seen for a reduction in RPE by approximately 10% between music and no-music conditions (Edworthy, & Waring, 2006; Elliot, Carr & Orne, 2005; Nethery, 2002; Szemdra & Bacharach, 1998) and music has been consistently shown to improve time to volitional exhaustion especially in ergometer trials at lower exercise intensities (Atkinson, Wilson, & Eubank, 2004; Bharani, Sahu, & Mathew, 2004; Nakamura, Pereira, Papini, Nakamura, & Kokubun, 2010). In essence, the key role of music in recreational exercise is said to be one of lowering perceptions of exertion and thereby increasing the amount of work performed without a shift toward negative feeling states typically associated with exercise at low-to-moderate intensities (Karageorghis et al., 2011). However the effect or effect limitations of exercise intensity, and the possible attenuation to the stimulus effect on performance - especially with regards to higher-intensity endurance tasks - has recently started to spike interest in this field.

Regrettably the research on higher intensity exercise performances to date has been widely inconclusive, and somewhat divergent. In two separate studies, Tenebaum et al. (2004) and Macone, Baldari, Zelli and Guidetti (2006), the effects of music on a treadmill test to volitional fatigue were assessed. Both studies found no impact on endurance or perceptions of exertion. These results were partly predicted by the previously mentioned 'parallel processing' hypothesis which states that as exercise intensity increases, physiological cues predominate (Rejeski, 1985). The theoretical prediction being that physiological feedback would dominate the capacity of the nervous system at very high exercise intensities and thus overshadow the previously demonstrated effects of accompanying music in the lower exercise intensity domain.

Contradictive to this theoretical framework Bharani et al. (2004) conducted a very similar study to both Tenebaum and Macone's, where participants ran on a treadmill to volitional fatigue and this time lower RPE values under the music condition were reported. Another study which is interesting to note, conducted back in 1998 by Szmedra and Bacharach examined the effects of music during moderate-intensity running and the music condition showed lowered heart rate, blood pressure and perceptions of exertion. The confounding results across these studies highlight the need for more research on varying levels of exercise intensity. It appears that music can enhance the magnitude of improvement across exercise intensity, but the findings are not consistent. At all exercise intensities, but especially low-to-moderate, music has an ergogenic effect across a variety of exercise tasks including: running, rowing and cycling. However, is there an attenuation to the stimulus effects above a certain intensity threshold or is the body of research in the area simply not complete? Although the internal physiological feedback associated with exercise induced fatigue during higher intensity exercise is thought to dominate the perceptual field this too is a theory which can be debated. The previously determined capacity of music to enhance positive feelings during exercise performance can alter the way judgements are made about the exercise experience and may affect perceptions at a higher exercise intensity. This is not an illogical idea as high-intensity exercise has in the past shown to be associated with significant decrements in affect (Ekkekakis, Hall, & Petruzzello, 2004). Future research endeavours should focus on pinpointing exactly whether the effects of music on exercise performance can extend into higher-intensity exercise. Evidence has been revealed to suggest that although the music may not be able to alter what one feels when working at high intensities, it still may be able to impact how one feels (Hardy & Rejeski, 1989; Hutchinson et al., 2011; White & Potteiger, 1996).

D. Purposed mechanisms

There are a couple recurring theories underlying a potential rationale or mechanism behind the many benefits that have been reported when using music during exercise performance. It has been hypothesised that music may allow the individual to separate thought from feelings. This divergence, or 'attentional switching' can change one's perception of unpleasant feelings; therefore the sensations of fatigue during the exercise are minimalized (Atkinson et al., 2004;

Edworthy & Haring, 2006; Yamashita et al., 2006; Murrock & Higgins, 2009). This process is comparable to the cognitive strategy of dissociation and supports the idea that it is mainly a psychological response to the music which mediates the effects (Rejeski, 1985). A second hypothesis however proposes that the divergent factor (i.e. music) is somehow able to alter psychomotor arousal and, therefore can act as either a 'psycho-physical' stimulant or a sedative prior to and during physical activity (Szmedra & Bahanach, 1998; Yamamoto et al., 2003; Schucker et al., 2009). Finally a third theory postulates that during continual submaximal activity, an individual is predisposed to respond to rhythmical elements; the result being a synchronization between the music tempo and the performer's movement making physical activity or exercise a more harmonious or less stressful experience (Rendi et al., 2008 & Waterhouse et al., 2009). It remains to be seen however which of the above hypotheses is the most accurate or if there is a better explanation. The exact mechanisms underlying the effects and effect limitations of music use during exercise performance are still poorly understood. Future research endeavours should focus on differentiating psychological and physiological mechanisms for the improved performance effects in an effort to identify exact mechanisms and potential physiological pathways, including but not limited to an investigation into the possible neurophysiological correlates of the musical response before, during and after exercise.

Central vs. Peripheral Fatigue

A widely debated topic in exercise science is the actual cause of exercise induced fatigue. Muscle fatigue is "an exercise-induced reduction in maximal voluntary muscle force, which may arise not only because of peripheral changes at the level of the muscle, but also because the central nervous system fails to drive the motor neurons adequately" (Gandevia, 2001). However, in many exercise physiology text books you will find a definition similar to this: fatigue during most forms of exercise is due to peripherally based, metabolite induced failure of skeletal muscle contractile function, 'peripheral fatigue,' independent of the reduced skeletal muscle activation by efferent output from the motor cortex of the central nervous system (CNS); so-called 'central fatigue' (Edwards R.H.T., 1983). This suggests that exercise terminates as a result of physiological and biochemical events initiated when biological limits of the body are exceeded with a resulting loss of homeostasis, termed the 'catastrophe theory' which can be traced back to studies conducted in the early 1900s (Fletcher & Hopkins, 1907; Hill, 1924). Current research, especially previous publications by T.D. Noakes have concluded that there is actually little published evidence to support the theory that fatigue occurs only after physiological homeostasis fails. There is a new postulate that suggests fatigue in any type of exercise may form part of a regulated, anticipatory response co-ordinated in the subconscious brain; ultimately regulated by the central nervous system or an entity known as 'the central governor' (Noakes & Gibson, 2004).

Noakes and his colleagues are not the only group who has chosen to challenge the old paradigm of exercise physiology by emphasising the crucial role played by the brain in the regulation of exercise performance. Marcora (2008) also questioned the validity and practicality of the catastrophe model, though he also contests the central governor model, stating that it is internally inconsistent and unnecessarily complex. Their theory is termed the psychobiological model of exercise tolerance. This model is based on the premise of effort-related-decision-making, a conscious contribution of the central nervous system which can provide a unifying theory of exercise tolerance. This is in direct contrast with the traditional physiological model of fatigue and exercise performance which, despite almost a centennial of research, has yet to identify the undisputable peripheral "exercise stopper" and is also congruent with work done by Gandevia (2001).

In light of recent works it is clear that the popular model of peripheral fatigue alone is unable to explain a wide range of common observations from both laboratory studies and from real world competitive sports (Noakes, 2000). The strongest support for this idea comes from findings that fatigue develops in all forms of voluntary exercise without evidence of complete motor unit recruitment in all muscles involved in the activity, a previously held assumption of any strictly peripheral model so that any possible contribution for the CNS could be ignored (Lindstedt & Conley, 2001). Presently the consensus seems to be that there is no one global mechanism of muscle fatigue but an interplay between both peripheral and central factors. However, some suggest that the central nervous system or 'central fatigue' paradigm may be the foremost controller of exercise performance (Gandevia, 2001; Kayser, 2003). Future research endeavours should consider these new suggested fatigue models when attempting to better understand possible physiological mechanisms that may explain the beneficial effects seen through the use of music as an external stimulus in exercise performance.

Conclusion

The prevailing belief is that music facilitates exercise performance by reducing sensation of fatigue, there is an agreement among the previous studies that listening to music during exercise does result in positive effects on performance as a result of influences on behavioural, psychological, psychophysical and physiological states of exercise participants (Atkinson et al. 2004; Bharani et al. 2003; Crust & Clough, 2006; Karageorghis, Jones, Priest, Akers, Clarke, Perry et al., 2011; Edworthy & Waring 2006; Karageorghis et al., 2009; Terry & Karageorghis, 2011; Szmedra & Bacharach 1998; Yamashita et al. 2006). However, many methodological limitations have been brought to light especially in the studies conducted prior to the mid-1990s which has led to some variable work quality and produced equivocal findings. The more recent studies are now attempting to examine more closely the possible 'psychophysical' effects of music in the exercise setting with help from recent developments and a better conceptual understanding and standardization of music selection, among other variables. Some limitations are inevitable, especially in a relatively new field of research, but it is crucial that future researchers learn from previous design errors. Researchers seem to be more aware now of the inherent subjectivity of the stimulus under investigation and the complexity of its effects. Future research should focus on the extent to which stimulus effects are moderated or attenuated by intensity of exercise. Especially with regards to high intensity exercise and that above anabolic threshold, as the select number of studies done to date are conflicting and the association between music and improvements in endurance performance at low-to-moderate intensities are clear. There is also a definitive need for more mechanistic research in this developing field. The 'psychophysical' effects of music in the exercise setting have been illustrated but the distinction between the psychological and physiological effects is still absent from the literature. The neurophysiological correlates of the musical response has great potential and further exploration is necessary to evaluate proposed mechanisms such as 'attentional switching' (Rejeski, 1985) and the potential role played by the central nervous system in by passing peripheral metabolite induced signs and feelings of fatigue. In closing, this review of current literature illustrates that music does have a functional role in the exercise environment, with the capacity to exert beneficial psychological, behavioural and ergogenic effects across a wide range of exercise tasks (Karageorghis & Priest, 2012B). Nonetheless, there is still work to be done in order to get a more clear understanding of potential underlying mechanisms, whether they are psychological or physiological in nature and what the stimulus effect limitations are.

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CHAPTER 3: CO-AUTHORSHIP STATEMENT

My role in developing, and preparing this thesis is underlined in the following statements:

1) **Design and identification of the research proposal:** Previous work conducted by Dr. David Behm, Dr. Fabien Basset, and Dr. Duane Button; along with a series of work conducted by Dr. Costas I. Karageorghis, produced the initial interest in the present research manuscript and topic. Dr. Behm, Dr. Basset and I discussed and developed the current methodology for the research project.
2) **Practical aspects of research:** Raw data was collected by the primary author with the assistance of another graduate student in the laboratory Ms. Kathleen Sullivan.
3) **Data Analysis:** Under Dr. Behm and Dr. Basset's supervision, I conducted all the procedures involved in data reduction and data analysis.
4) **Manuscript Preparation:** I prepared the current manuscript under the supervision and guidance of Dr. Behm and Dr. Basset.

CHAPTER 4: THE EFFECT OF HIGH TEMPO MUSIC AS AN EXTERNAL STIMULUS DURING HIGH INTENSITY EXERCISE

This is an original manuscript and is not previously published, nor is it being considered elsewhere until a decision is made as to its acceptability by the *School of Graduate Studies at Memorial University of Newfoundland.*

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ABSTRACT

Evidence indicates that music can have a psychological effect by decreasing rate of perceived exertion and increasing exercise enjoyment. However, it has yet to be concluded whether listening to music affects the physiological responses to exercise, specifically with respect to high intensity or maximal work efforts. The purpose of this study was to assess the following physiological responses: heart rate (HR), ventilatory kinetics, time to task failure (TTF) and blood lactate (BL), as well as perceived exertion; while exercising and listening to high tempo music, all set at a tempo of 130 bpm. The exercise entailed interval training at 80% of an individual's peak power output (PPO) as assessed during an incremental maximal oxygen consumption (VO_{2max}) test on a stationary bicycle. The main finding in this study was that the participant's TTF when listening to music during their exercise performance was significantly greater ($p<0.05$), by one minute, than when exercising without music. Exercise heart rate was not significantly affected by music, however heart rate recovery was significantly faster by 13 bpm following the music condition ($p<0.05$). Additionally, participants had higher blood lactate levels and they rated their perceived exertion to be lower at the same or greater workloads when listening to music ($p<0.05$). Lastly, a higher breathing frequency was recorded with music ($p<0.05$). The results demonstrate that listening to music during high intensity exercise results in physiological changes. The results also support the theory that music can contribute to prolonged exercise durations at higher intensities with lower perceived exertion.

INTRODUCTION

Music has long been thought to affect the senses (Szmedra & Bacharach, 1998). In turn many believe that music as an external divergent stimulus during exercise is able to influence exercise enjoyment and can even act as an aid in exercise performance (Karageorghis & Priest, 2012A/B). The literature suggests that carefully selected music is able to promote ergogenic and psychological benefits during exercise. There are three recurring explanations underlying the rationale behind these benefits and how music might be used to motivate the physically inactive or promote exercise adherence in the general public. First, music may allow the individual to separate thought from feelings. This divergence can change one's perception of unpleasant feelings, narrowing the performer's attention. Therefore the sensations of fatigue during the exercise are minimized (Atkinson et al., 2004; Edworthy & Haring, 2006; Yamashita et al., 2006; Murrock & Higgins, 2009). This process is comparable to the cognitive strategy of dissociation and tends to support the idea that music will have a greater effect on the psyche than on physiological responses (Rejeski, 1985). The second hypothesis states that the divergent factor (i.e. music) will somehow alter psychomotor arousal (movement or muscular activity associated with mental processes) and, therefore can act as either a stimulant or a sedative prior to and during physical activity (Szmedra & Bahanach, 1998; Yamamoto et al., 2003; Schucker et al., 2009). The third theory postulates that during continual submaximal activity, an individual is predisposed to respond to rhythmical elements (music being one of many rhythmical patterns); the result being synchronization between the tempo and the performer's movement making physical activity or exercise a more harmonious or less stressful experience (Rendi et al., 2008 & Waterhouse et al., 2009). Although, there is a growing consensus in exercise-related research fields that using music has some benefits such as improved mood, arousal control, reduced rate of perceived exertion (RPE) and dissociation from feelings of fatigue, it remains to be seen which of the above hypotheses is the most accurate or if there is a better explanation. The exact mechanisms underlying the effects of music, often referred to as the divergent stimulus, are still poorly understood.

The available evidence on this topic is congruent and demonstrates that this divergent stimulus can and does have a consistent and measurable effect on psychological states and even behaviours that can positively influence performance by improving or increasing endurance and/or exercise enjoyment. The literature shows an influence on attention, the ability to trigger a range of emotions, affect mood, increase work output, and encourage rhythmic movement (Atkinson et al. 2004; Karageorghis, 2008; Scherer, 2004; Terry & Karageorghis, 2011; Yamashita et al., 2006). In many ways the ergogenic effects of music on performance can be thought of similar to that of a sports drink or an aerodynamic body suit, both of which are legal performance enhancing aids (Karageorghis & Priest, 2012). However, a vast majority of the current research has been focused on the psychological effects of music on exercise, mood, and emotion, and affect. The 'psychophysical' effects that have been examined are limited mainly to a psychological evaluation of the physiological processes that are occurring in the body when fatigued, a perception of efforts, which in almost all cases involves the Borg's Ratings of Perceived Exertion scale (RPE). The actual physiological rationale for the effect of this divergent stimulus during exercise has not been extensively studied and most available information on the topic is still equivocal.

The effects of music on exercise in the low-to-moderate range of exercise intensities, referred to as submaximal, is a common trend in the literature. In fact, this is where the most compelling case for a clear association between music and performance improvements has been made. The general conclusion is that music is more effective at lower exercise intensities owing to the fact that physiological feedback dominates the capacity of the nervous system at very high intensities (Rejeski, 1985; Tenenbaum, 2004). However, this idea plays on the popular theory that exercise, especially at high intensities, is limited by peripheral metabolite induced failures of the skeletal system or so-called 'peripheral fatigue.' This theory alludes to the cause of fatigue being completely independent of the central nervous system, which is a widely debated topic among exercise physiologists. In fact, it has been shown that peripheral fatigue alone is not able to explain some commonly seen observations in both laboratory and real world exercise or athletic experiences (Noakes & Gibson, 2004). Despite this, only a few studies have looked at higher intensity exercise bouts and the effect of music as an external stimulus. Unfortunately, a couple of these studies show methodological weaknesses and a misuse of music terminology resulting in some incongruent results (Bharani, Sahu & Matthew, 2004; Crust & Clough, 2006; Nakamura et al., 2010; Schie, Stewart, Becker & Rogers, 2008). In contrast some recent studies using 'supra-maximal' exercise, such as a Wingate test, have shown significant improvements in peak power output and decreases in fatigue index with the use of music as an external stimulus (Brohmer & Becker, 2006; Haluk, Turchian, & Adnan, 2009). This seems to directly contradict the previous conclusions drawn by researchers that the 'distraction effect' of music is attenuated at higher exercise intensities (>70% VO_2 max) due to the internal feedback dominating the capacity of the respective afferent nervous system (Karageorghis, Terry, Lane, Bishop & Priest, 2011). More importantly however, it highlights some significant gaps in the literature with regards to the so-called intensity limitations of music's benefits and the actual mechanisms that result in music's ergogenic effects on exercise performance. Is it purely psychological, psycho-physiological or physiological in nature? Further research is still necessary in order to draw decisive conclusions.

Therefore, the primary goal of this study was to validate the hypothesis that listening to high tempo music (130 bpm) while performing high intensity bouts of cycling would improve a participant's time to task failure (TTF) and have a positive effect on the commonly seen physiological signs of fatigue. We intend to simultaneously test the hypothesis that the causes of fatigue, which develops especially during high intensity exercise of short duration, may not be solely peripherally based (metabolite induced failure), but may in fact also have something to do with the command of the central nervous system. We plan to achieve this by investigating the effects this high intensity aerobic exercise task on muscular strength and endurance by measuring pre/post task contractile properties and electrophysiological measures (MVC, Muscle Activation, Rate of Force development).

METHODS

Subjects

Sixteen healthy and recreationally active individuals (Eight males: age 24.5 ± 3.4 yrs, mass 75.2 ± 7.4 kg, height 178.3 ± 6.2 cm, VO_{2max} 4.1 ± 0.4 L/min and eight females: age 23.1 ± 3.0 yrs, mass 65.7 ± 4.7 kg, height 163.9 ± 5.3 cm, VO_{2max} 3.4 ± 0.3 L/min) volunteered from the university community to participate in this study. All the participants filled out a Physical Activity Readiness Questionnaire form from the Canadian Society for Exercise Physiology to determine their general health status. If any health problems were reported, they were excluded from the study, this occurred in only two instances where the participants felt faint at the sight of their own blood during blood lactate recording. The participants read and signed a consent form before commencement of the study, the participants were naïve to the main study goals and hypothesis but were informed about the intervention that would be used. The Memorial University of Newfoundland Human Investigations Committee approved the study.

Experimental Design

Participants took part in a randomized cross-over design study consisting of one testing session and two experimental sessions separated by a minimum of two days. During the first session all participants underwent a maximal oxygen uptake determination test (V□O_2 max) in order to individualize the intensity level of the following two sessions, and to familiarize them to the testing protocols. These testing protocols are described below as the five pre-exercise bout measurements. The next two experimental sessions consisted of performing high intensity (80% of PPO) interval cycling bouts with or without music. Five pre-exercise bout measurements were performed at the beginning of each experimental session. Participants were first asked to sit and relax / rest for a five minute silent period; at the end of the five minute period their resting heart rate (RHR), resting blood lactate level (RBL) and finally their resting blood pressure (RBP) were recorded. Next the participants' right leg was prepped for electrode placement, as the last two pretest measures were electrophysiological measures using low levels of electrical stimulation and isometric contractions to record forces and activation (maximal voluntary contractions [MVC]) at the quadriceps muscle. After that, participants randomly completed one of the two experimental conditions (music or no-music). Participants then sat on a stationary bike while their feet were secured and they donned an oro-nasal facemask, to record cardio-respiratory parameters for the duration for the experiment. The experimental protocol involved the participants performing continuous four minute bouts of high intensity (@ 80% PPO) cycling intervals with a work to rest ratio of two to one, meaning every four minute bout was followed immediately by a two minute active rest period (@ 40% PPO). Every minute during the four minute bout of exercise the participant was asked to rate their RPE on the Borg scale, values 6 through 20; then without delay following each four minute bout the participants heart rate and blood lactate level were recorded. Heart rate was also recorded on a monitor continuously throughout the session. It was recorded beat by beat using a telemetric heart rate monitor (Polar S810i, Polar Electro, Kempele, Finland) and watch system, which stored the data until it could be transferred immediately after the session to a personal computer. The participant continued to exercise until reaching one of the following three criteria: volitional fatigue, reporting an RPE of 19 or higher (to allow for discrepancies in the inherent subjective of the rating scale), or no longer being able to keep a cadence above 60 rpm. Once exercise ceased the four of five pre-exercise bouts measurements (minus blood pressure) were repeated. Participants were released from the experiment following an adequate recovery period (i.e. resting heart rate ≤ 100 bpm).

Instrumentation

Force Measurement. For all voluntary and evoked contractions, subjects were seated on a bench with their hips and knees flexed at 90°. The subject's right lower limb was inserted into a padded strap at the ankle and attached by a high-tension wire to a Wheatstone bridge configuration strain gauge (LCCA 250, Omega Engineering Inc., Don Mills, Ontario, Canada). All voluntary and evoked forces were detected by strain gauges, amplified (DA 100: analog-digital converter MP100WSW, Biopac Systems Inc., Holliston, MA), and monitored on a personal computer. Data were stored on a computer at a sampling rate of 2,000 Hz. Data were recorded and analyzed with a commercially designed software program (AcqKnowledge 4.1, Biopac).

Electromyography (EMG) and Evoked Stimulation. Thorough skin preparation for the electrodes included shaving areas where electrodes would be placed, removing dead epithelial cells with an abrasive paper around the designated areas and then cleansing with an isopropyl alcohol swab. Two surface EMG recording electrodes (Meditrace Pellet Ag/AgCl discs and 10 mm in diameter, Graphic Controls Ltd., Buffalo, NY) were placed approximately 2 cm apart over the midpoint of the right quadriceps, the muscle belly of rectus femoris, between the anterior superior iliac spine and the top of the patella with a ground electrode placed on the head of the fibula (Blanc & Dimanico, 2010). All electrode placements were marked with indelible ink in order to ensure accurate and consistent surface electrode placement in subsequent sessions. Stimulating electrodes, 4–5 cm in width, were constructed from aluminum foil, coated with conduction gel, and immersed in a saline solution. Surface-stimulating electrodes were secured with Lightplast Pro® elastic adhesive tape over the proximal portions of the *vastus medialis, vastus lateralis*, and *rectus femoris* as well as over the distal portion of the quadriceps (*vastus medialis* and *vastus lateralis*). Peak twitch torques were evoked with electrodes connected to a high-voltage stimulator (Stimulator Model DS7H1, Digitimer, Welwyn Garden City, Hertfordshire, UK). The amperage was increased from 10 mA-1A of 50-microsecond duration stimulation until a maximum twitch torque was achieved, while voltage (200 V square-wave pulse) was held constant.

Cardio-respiratory Measurements. Oxygen uptake (VO2), carbon dioxide output (VCO2), breathing frequency (Bf) and tidal volume (VT) were continuously collected with an automated breath-by-breath system (Sensor Medics® version Vmax ST 1.0) using a nafion filter tube and a turbine flow meter (opto-electric). Respiratory exchange ratio (RER) and minute ventilation (Ve) were calculated as the product quotient of CO2 on O2 and of Bf by VT, respectively. Heart rate (HR) values were transmitted with a Polar heart rate monitor (PolarElectro, Kempele, Finland). Prior to testing, gas analyzers and volume were calibrated with medically certified calibration gases (16.0%O2 and 3.98% CO2) and with a three-liter calibration syringe. In addition, to ensure accurate calibration of the cart, a propane gas calibration was performed to assess the sensitivity of the oxygen and carbon dioxide analysers.

Lactate Measurements. All lactate measurements were taken using the Lactate Pro (LP, Arkray KDK, Japan) a hand-held portable analyzer which measures whole blood. A blood sample of ≥ 5 μL was taken from the participant's fingertip using a spring loaded lancet, which was provided with the Lactate Pro system. Lancets were discarded and replaced following each use. Sample analysis time took 60 seconds and then the values were recorded. The company supplied a check strip to confirm that the analyzer was operating correctly, and a calibration strip that provided a non-quantitative indication of analyzer accuracy which was used at the beginning of each testing session to ensure validity of the measures.

Cycle Ergometer. All exercise protocols were performed on the Velotron Dynafit Pro cycle ergometer (RacerMate, Inc., Seattle, WA). Factory calibration of the cycle ergometer was verified using Velotron CS software (RacerMate, Inc.) and the Accuwatt rundown verification procedure. Individual positional adjustments (saddle and handlebar height) were made before the first exercise test and were replicated for all subsequent exercise tests. Visual feedback of power output and pedalling rate (RPM) were available to the participants during each exercise session.

Music. All participants listened to the exact same playlist of popular music which was set to a 130 bpm tempo; meaning each song was not originally 130 bpm but was altered to keep a consistent tempo throughout the playlist. Music was played through an Ipod® nano using 'earbud' type head phones and volume was held constant for each participant at 50% of the maximum volume approximately 65 decibels, based on manufacturer specifications of maximum volume being 130 decibels.

Testing Procedure

Pretest. After the initial pretest measures, RHR, RBL and RBP were recorded, electrodes were put in place and the participants were seated on the bench with their ankle secured in a padded strap and we began by determining the participants' peak twitch torque. Following this the participants were given a three minute rest period during which time MVC's and how to perform an accurate MVC were explained and demonstrated for the participant. Prior to attempting MVCs, participants were asked to perform approximately three - five submaximal isometric leg extension contractions for both practice and warm up to ensure no one was injured. Participants then were requested to perform at least two four second isometric MVCs to determine their maximum isometric force output, which were preceded by a twitch and followed by a twitch of the same strength which was previously determined to evoke a maximum twitch torque. To ensure a consistent maximal effort, the subjects proceeded with the rest of the protocol only if there was less than a 5% difference between the two MVCs. If this parameter was not met a third and final MVC was performed to ensure accuracy of results.

Exercise Bouts. Following the completion of the pretest protocols the participants were moved to the cycle ergometer. Next the participants were given an explanation of the 20 point Borg RPE scale and told that if at any time they wished to stop exercising because they were too tired they could do so. After participants were fitted with an armband that held an Ipod® nano and ear bud type headphones, (headphones and armband were worn regardless of condition) the facemask and mesh headpiece were secured next and hooked up to the Metamax 3B portable metabolic system (Sensor Medics® version Vmax ST 1.0). Each participant then had a five minute warm up period where they were instructed to keep a cadence equal to or greater than 60 rpm which was displayed on a large computer screen in front of them; they were also instructed that this cadence needed to be maintained for the duration of the exercise protocol or they would be asked to stop. This is also the time in the experiment where the music was turned on for the music condition. The resistance for the warm up was set at 40% of their PPO as determined during their $\dot{V}O_2$ max test in the first session of the experiment; PPO was verified for each participant by graphically determining if there was a plateau in peak $\dot{V}O_2$, adjustments were made where necessary thus resistance was different for each participant. Immediately following the warm up period the resistance was increased to 80% of the PPO as seen during their $\dot{V}O_2$ max test and they maintained this workload for four minutes. At one minute intervals the participants were asked to report their RPE value and at the end of the four minutes of work blood lactate levels were assessed. A two minute active rest period started immediately following the end of the four minute bout with the same resistance that was used for the participants warm up. When the participants reached task failure, a final RPE was recorded and a final blood lactate sample was taken before they removed the Ipod® and were quickly and carefully moved back to the bench to perform subsequent MVC's.

Post-test. Three minutes after the participant finished their intervals on the cycle ergometer they were seated back on the bench with their ankle secured in the padded strap and were asked to repeat the same twitch-MVC-twitch protocol. Participants were then asked to stay in position but relax for five minutes, at the end of this rest period a final heart rate and blood lactate level were recorded and the twitch-MVC-twitch protocol was repeated for one last time.

Statistical Analysis

All statistical analyses were conducted using Sigmaplot (version 10.0; Systat Software Inc) and Microsoft Office Excel spreadsheets. All rate of perceived exertion, time to task failure, blood lactate and ventilatory kinetics measures (BF, V_T, V_E, VO_2, VCO_2, etc.) were analyzed with a 2-way analysis of variance [ANOVA] (2 x 3) to determine whether there were significant main effects or interactions for condition (music or no music), or time (pre-, post, 5 minutes post-exercise); initially a 3-way ANOVA with gender as a factor was performed but there was no significant differences found and gender was removed. All electrophysiological measures (MVC, Muscle Activation, Rate of Force development, etc.) were analyzed with a 3-way ANOVA (2 x 2 x 3) to determine whether there were significant main effects or interactions for gender (male or female), condition (music or no music), or time (pre-, post-, 5 minutes post-exercise). Differences were considered significant at $p<0.05$. If significant main effects or interactions were present, a Bonferroni (Dunn) procedure was conducted.

RESULTS

Participants were asked to complete as many four minute intervals at 80% of their peak power output on a cycle ergometer, as measured during a VO_2 max incremental test, as possible. As each participant exercised to volitional fatigue, each testing session was a different length of time; therefore, some variables seen below were collapsed over time or reported as a percentage of TTF.

Rate of Perceived Exertion

There was a significant difference ($p<0.05$) observed for the participants change in RPE over time for the latter two minutes of the intervals. In the music condition at the third minute of an interval, RPE increased on average 3.3 ± 1.2 points and at the fourth minute the average increase was 4.1 ± 1.5 points. This change was lower than the average increase seen in the no-music condition, which at three minutes was 3.8 ± 1.3 points and at the fourth minute was 4.8 ± 1.6 points (See Figure 1). There was no main effect or interactions for condition or time for the absolute values of RPE recorded per minute of exercise.

Time to Task Failure

There was a main effect for time and condition for time to task failure ($p<0.05$). The average TTF in the music condition (10:18 ± 3:24 mins:secs) was significantly longer ($p<0.05$) than the average TTF in the no-music condition (9:18 ± 3:19 mins:secs). These mean reported times did not include the time spent in active rest (see Figure 2). Therefore on average participants in the music condition completed approximately 2.6 intervals and exercised for one minute longer while participants in the no-music condition only completed approximately 2.3 intervals.

Breathing Frequency

There was a main effect for condition ($p<0.05$) on the participants breathing frequency in the music condition (Figure 3). Average breathing frequency was higher in the music condition (43.2 ± 8.7 breath.min^{-1}) than in the no-music condition (38.7 ± 8.2 breath.min^{-1}). There was also a main effect for time, with breathing frequency increasing over time in the music condition (start 35.5 ± 8.6 breath.min^{-1} to end 47.7 ± 8.3 breath.min^{-1}) and in the no music condition (start 34.7 ± 8.4 breath.min^{-1} to end 43.3 ± 8.3 breath.min^{-1}).

Heart Rate

There was main effect for time and condition on heart rate however HR during exercise and immediately post-exercise (music condition 183.1 ± 10.3 bpm and no-music condition 181.1±

9.1 bpm) were not significantly affected by the music stimulus. An interaction effect ($p<0.05$) was seen between conditions for heart rate five minutes post-exercise, with a lower HR recorded in the music condition (99.6 ± 7.6 bpm) than in the no-music condition (112.6 ± 10.6 bpm), (Figure 4).

Respiratory Exchange Ratio

There was a main effect for time and condition on respiratory exchange ratio however there were no significant differences found 25%, 50% or 75% of TTF during the cycling intervals between the music and no music conditions. An interaction effect ($p<0.05$) was seen between conditions at TTF (Figure 5). The RER at TTF in the music condition (0.99 ± 0.03) was significantly higher than the RER observed at TTF in the no-music condition (0.92 ± 0.02).

Blood Lactate

There was a trend ($P=0.08$) for the average blood lactate levels post-exercise, at TTF, in the music condition (13.5 ± 2.7 $mmol.L^{-1}$) blood lactate levels were higher than those post-exercise in the no-music condition (12.0 ± 3.0 $mmol.L^{-1}$). There were no significant differences found pre-exercise or during exercise across conditions.

Contractile Properties

There was a negative main effect for time ($p<0.05$) for all contractile properties: MVC force production, evoked peak twitch force, potentiated twitch force and difference between evoked and potentiated contractile forces; pre and post-exercise. There no significant differences or interactions found five minutes post-exercise. There was a main effect for gender ($p<0.05$) for all contractile properties; male and female. There were no significant differences or interactions found between conditions; music and no-music (see Table 1 & 2).

DISCUSSION

The primary purpose of this study was to determine the effects of listening to high tempo music (130 bpm) while performing high intensity bouts of cycling. The key findings were consistent with the hypothesis, which included an increase in TTF, a decrease in RPE, an increase in BF and RER, as well as a faster heart rate recovery post-exercise in the music condition. Participants were able to exercise longer and work harder while rating their perceived exertion lower, as well as recover faster when they were listening to high tempo music.

Music has previously been reported to have beneficial effects on submaximal physical performance, specifically with regards to aerobic exercise (Elliott, Carr, & Savage, 2004; Ghaderi, Rahimi, & Azarbayjani, 2009; Karageorghis, Mouzourides et al., 2009; Karageorghis & Terry, 1997; Simpson & Karageorghis, 2006; Szmedra & Bacharach, 1998; Waterhouse, Hudson & Edwards, 2009); however fewer studies have actually investigated such effects on high intensity aerobic exercise (Haluk, Turchian, & Adnan, 2009; Macone, Baldari, Zelli, & Guidetti, 2006; Rendi, Szabo, & Szaba, 2008; Tenenabum et al., 2004). The general conclusion has formerly been that music is more effective as an ergogenic aid at lower exercise intensities. The rationale being that physiological feedback tends to dominate the capacity of the nervous system at very high exercise intensities (Rejeski, 1985; Hardy & Rejeski, 1989). The results of our study showed that the participants (exercising at 80% of their PPO) were able to exercise for longer with the music stimulus even when physiological feedback is thought to dominate.

Although it is commonly thought that the positive effects of music on how one feels during exercise is limited by or attenuated by the level of intensity (Karageorghis & Terry 1997; Rejeski, 1985; Tenebaum, 2001), the results of our study are congruent with the concept that suggests you do not need to 'distract' the exerciser from the sensations of fatigue, you simply have to change their perception of this fatigue for them to perform better at the higher intensities (Hardy & Rejeski, 1989; Karageorghis et al., 2009). Specifically, participants in both conditions attained similar RPE ratings; however the rate of change for those listening to the high tempo music was much smaller. Meaning that in the third and fourth minutes, near the latter stages of their intervals the participants did not perceive as great of an increase in exertion even though physiological markers indicated that they were working harder. Thus, the music was able to somehow change their perception of this fatigue towards a more positive evaluation.

Another possible explanation for the participant's increased TTF while experiencing a build-up of peripheral metabolites – as noted by an increase in blood lactate and a higher RER – and still reporting a lower perceived exertion can be attributed to the contributions of the central nervous system and the theory of its ability to control or attenuate exercise performance. Noakes and Gibson (2004) suggested that it is quite difficult to understand how peripherally based fatigue could develop in all muscle fibers when only some are actively recruited at the point of fatigue. Therefore it only calls to reason that the central nervous system must have some control over exercise performance (Kayser, 2003; Noakes, 2000). The results of our study regarding breathing frequency, only further support this suggestion. Breathing frequency is controlled by the autonomic nervous system, in the respiratory centers located in the medulla oblongata in the lower brainstem, functioning largely below the level of consciousness (Bechbache & Duffin, 1977). This means that at some point during the cycling intervals, performed with high tempo music, this part of the brain stem was subconsciously triggered. As a result the participants breathing frequency was elevated which could be an indication of improved buffering, as blood lactate is buffered by the haemoglobin resulting in greater CO_2 and a stronger impulse to breathe. Although the exact mechanism for this phenomenon is unclear, these findings do support the idea that further research into the underlying *physiological* mechanisms involved with the beneficial effects of music on exercise performance are warranted.

Similar to most of the current literature on this topic, heart rate during exercise was not affected by the divergent stimulus, and there was no entrainment effect noted (i.e. no effect or synchronization of cadence as a result of tempo). However, there was an anomaly in our study which has to do with post-exercise recuperative effects of music in that participants who completed the cycling intervals with music had a faster heart rate recovery. There is very little known today about the impact of music on post-exercise performance. There are studies that attest to the capacity of music to relieve stress and improve affective states in non-exercise settings (Särkämö et al., 2008), still this is something that merits future research endeavours. Also interesting to note is that participants in this study had the music stimulus removed immediately at the end of their cycling intervals, however five minutes post-exercise their heart rates were significantly lower than those recorded in the no-music condition. This translates again to a possible effect of the music on the autonomic nervous system; whereby the altered interpretation of fatigue by the body as a result of the music stimulus also may have triggered a parasympathetic response, decreasing post-exercise heart rate faster. These results further support the theory that the central nervous system ultimately has the ability to control some types of exercise performance and aid in the ability to exercise for longer at higher intensities; unfortunately the verification of these theories were not within the scope of this investigation.

The secondary purpose of the investigation, which was performed simultaneously, looked at the effects of high intensity aerobic exercise on muscular strength and endurance. All contractile properties (pre- and post-exercise) were negatively affected which consistent with the hypothesis that high intensity aerobic exercise would have negative effects on muscular force production. This second part of the study also addressed a central debate in exercise science, whether the causes of fatigue are peripheral and metabolite-induced or central stemming from the central nervous system. Even with the increase length of time spent exercising and the increases in metabolite signs of fatigue there were no significant differences found between conditions (music and no-music) for all contractile properties. Thus, the cause of fatigue may not be solely peripherally based (metabolite-induced failure), indicating involvement from the central nervous system (CNS), which may be the predominant influence over volitional fatigue with this type of activity. Although we are suggesting that music had a predominant effect on the CNS, high intensity cycling with or without music showed to negatively impact muscle contractile properties. The non-detectable difference between conditions may simply indicate that despite one condition being longer, at task failure, peripheral mechanisms were similar. However, this alternative explanation still cannot rule out central fatigue. A superimposed twitch used during the MVC to calculate voluntary activation would have been beneficial if used in this study to assist in the clarifying central versus peripheral debate, unfortunately this was an afterthought. The present study illustrated decreases in MVC force production, evoked contractile force, potentiated twitch force and differences between evoked and potentiated contractile forces post-aerobic exercise. Other studies looking at the effects of aerobic exercise on the ability of acute contractile activity are limited but similar results have been reported with regards to concurrent endurance and strength training interfering or inhibiting strength development. This is especially true if the concurrent training period is too long and/or the training volume or intensity is too high (Hunter, Demment, & Miller, 1987; Leveritt, Abernethy, Barry, & Logan, 1999). One suggestion is that in maximal aerobic performance, the neuromuscular system is asked to produce power repeatedly in circumstances in which energy production is high, acidity in muscle is increased, and muscle contractility may be limited by this factor (Dudley & Djamil, 1985; Hickson, 1980). In a study by Ha¨kkinen et al. 2003, however, it was suggested that this may be associated with the limited changes in rapid voluntary neural activation of trained muscles. It is well established that peripheral responses to fatigue such as metabolite accumulation, and tension are transmitted to the CNS by chemoreceptors, mechanoreceptors, type II and IV pain afferents and other afferent systems (Edwards R.H.T., 1983). While music cannot directly modulate muscle contractile responses, music seems to have a positive effect on the perception and voluntary response to these fatigue related stimuli.

Although the research is somewhat conflicting when it comes to measuring the extent to which music can enhance exercise performance at maximal or near-maximal levels, this study demonstrated that listening to high tempo music (via headphones) during high intensity cycling intervals can alter an individual's perceived exertion. The idea of being able to alter perception is consistent with a vast majority of the current research, which is focused on the psychological effects of music on exercise, mood, and emotion, and affect. It is the 'psychophysical' effects or more prudently the physiological effects that have been noted in this study that should motivate future research endeavours. Research should continue to examine the potential benefits of using music for exercise performance in not only athletes and exercise enthusiasts but for the untrained and clinical populations as well. We showed an effect on the individuals in our study at the level of the central nervous system, which resulted in an alteration of both central and peripheral fatigue factors. If music can truly distract or disguise the peripheral signs of fatigue, to the extent where the central nervous system will allow the individual to work harder, breath harder, and induce more muscle fatigue, all whilst diminishing the feeling of discomfort, it only stands to reason that we might be able to tap into this avenue as a valuable asset to promote exercise enjoyment and increase exercise adherence for all.

CONCLUSION

Music is extremely complex, consisting of many elements: tempo, melody, rhythm and pitch. The human body is more complex, consists of: muscles, blood, organs and the most complex of all, a brain. As a result of these complexities, the physiological responses to music and how music affects the body's responses to exercise are not simple. As such, the exact physiological mechanisms behind the beneficial effects of music on exercise performance are still elusive. However, the present results support the idea that a physiological mechanism does exist and is likely related to the central nervous systems control over volitional fatigue at a level below consciousness. Therefore, further studies of the effect of music on exercise performance should focus on the physiological mechanisms responsible for the benefits, including potentially more invasive procedures (i.e. fMRI) as opposed to the psychological mechanisms and responses as they have been consistent within the literature.

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APPENDIX A – Figures & Tables

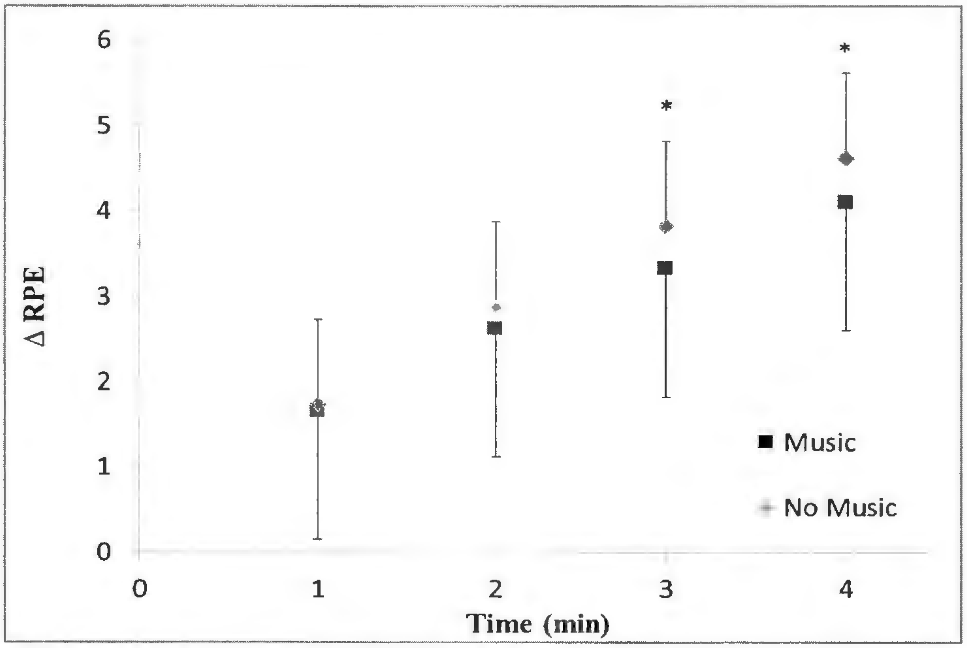

Figure 1. The average change in RPE over time during the four minute cycling intervals in conditions with music and without music, statistical differences between conditions denoted by $*p < 0.05$.

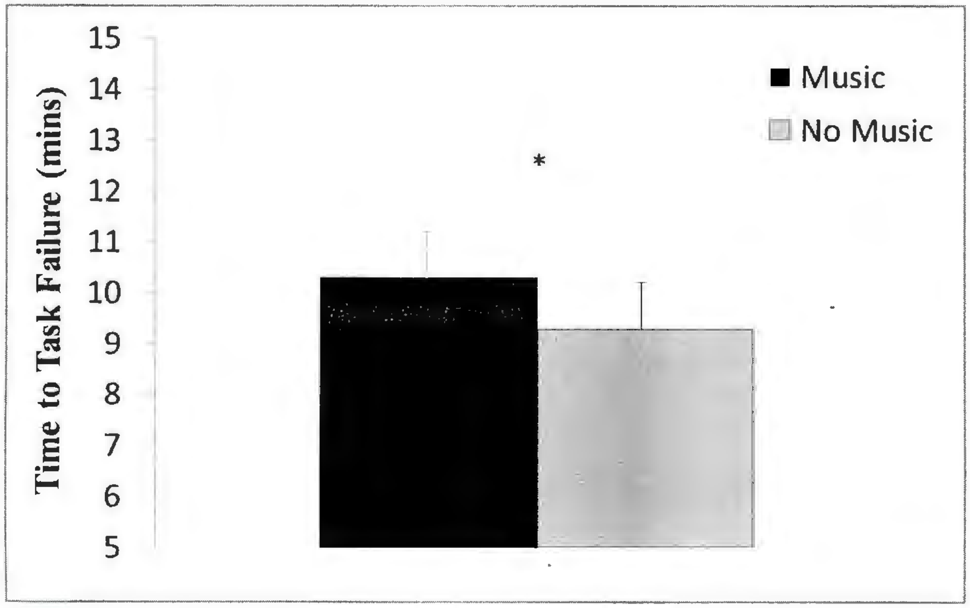

Figure 2. Bars represent differences in time to task failure (minutes) during cycling intervals in conditions with or without music collapsed over time with active rest periods removed. Asterisks represent significant differences at $p < 0.05$. Vertical bars represent SEs.

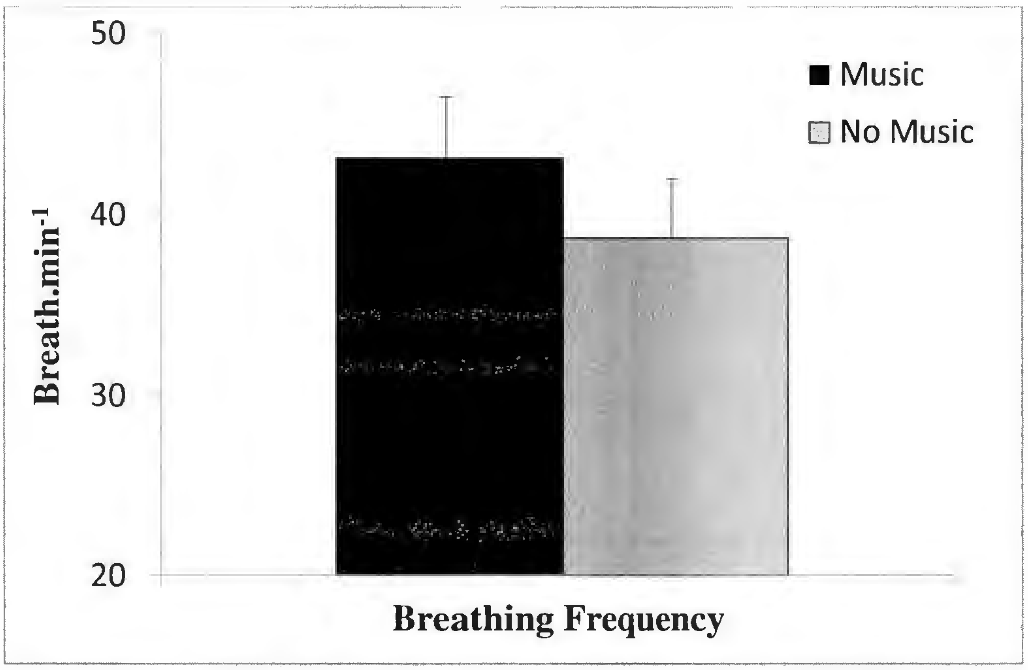

Figure 3. Bars represent differences in breathing frequency (Breath.Minute^{-1}) during cycling intervals in conditions with or without music. Asterisks represent significant differences at $p < 0.05$. Vertical bars represent SEs.

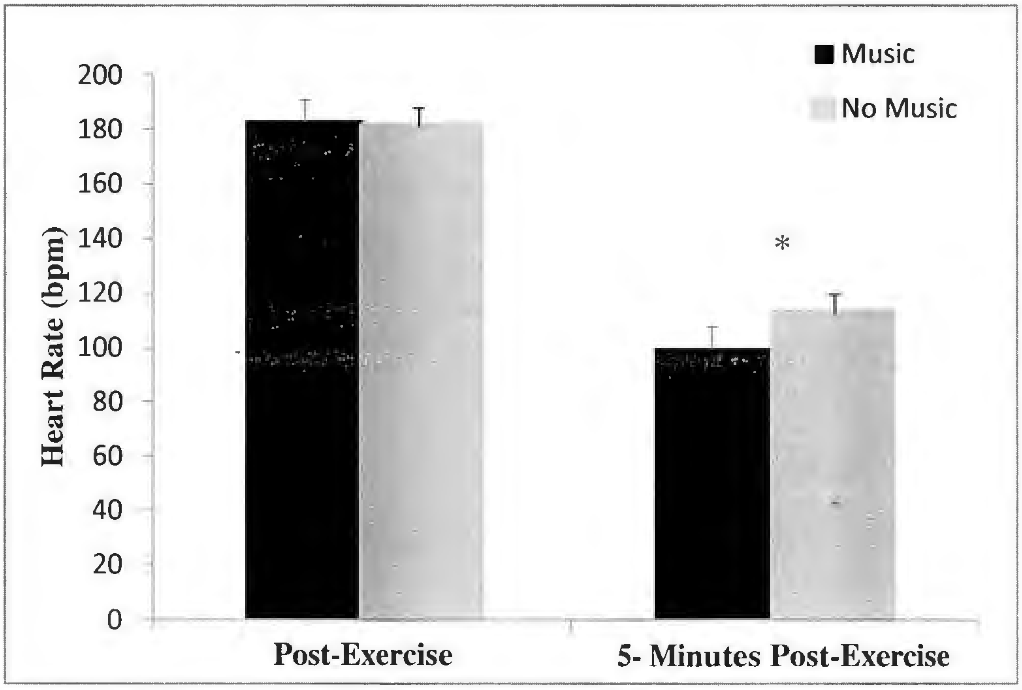

Figure 4. Bars represent differences in heart rate post- exercise and five minutes post-exercise (heart rate recovery) in conditions with or without music. Asterisks represent significant differences at $p < 0.05$. Vertical bars represent SEs.

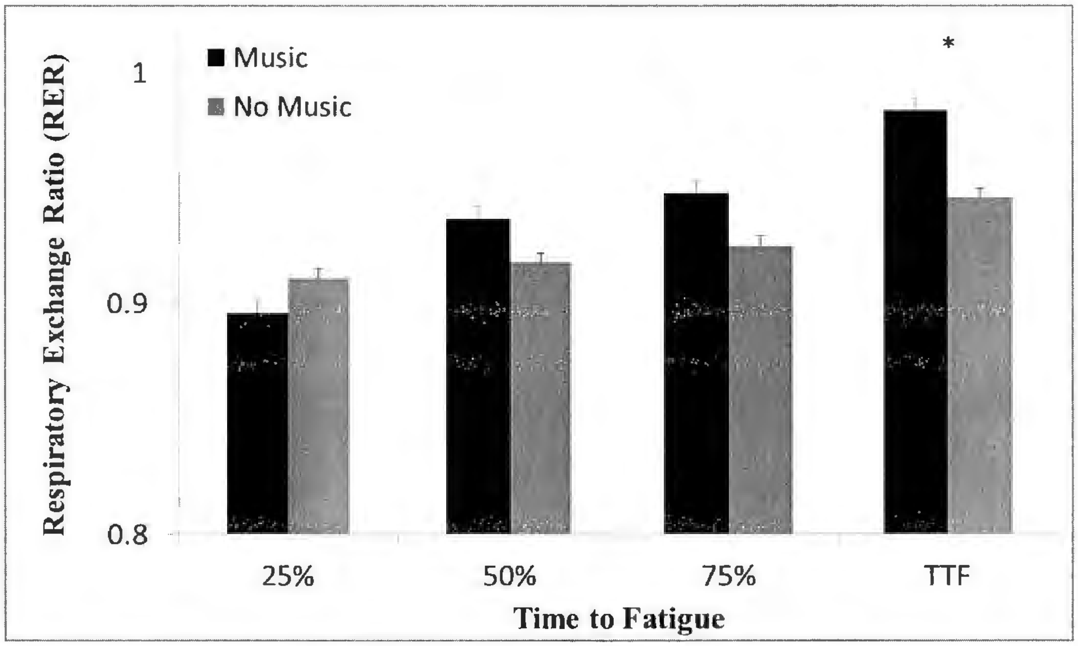

Figure 5. Bars represent differences in respiratory exchange ratio at a percentage of the participant's time to fatigue in conditions with or without music. Asterisks represent significant differences at $p < 0.05$. Vertical bars represent SEs.

Table 1. Main effect for time for all contractile properties, collapsed over both conditions for males (mean ± SD).

	Pre	Post	% Δ	*P*
MVC Force	56.8 ± 12. 8	47.9 ± 12.0	↓15.7	0.033
Evoked Peak Twitch Force	17.5 ± 8.1	10.9 ± 2.0	↓37.7	<0.001
Potentiated Twitch	21.9 ± 5.5	13.5 ± 3.0	↓38.4	<0.001
Δ Evoked and Potentiated	4.4 ± 1.8	2.6 ± 1.5	↓40.9	0.002

*Note *p* values listed above are for the main effect of time, for gender in all variables $p<0.001$.

Table 2. Main effect for time for all contractile properties, collapsed over both conditions for females (mean ± SD).

	Pre	Post	% Δ	*p*
MVC Force	36.8 ± 8.1	32.7 ± 8.3	↓11.1	0.033
Evoked Peak Twitch Force	11.1 ± 1.9	7.5 ± 3.2	↓32.4	<0.001
Potentiated Twitch	13.6 ± 2.2	9.7 ± 4.4	↓28.7	<0.001
Δ Evoked and Potentiated	2.49 ± 1.1	2.2 ± 1.9	↓11.6	0.002

*Note *p* values listed above are for the main effect of time, for gender in all variables $p<0.001$.

CHAPTER 5: SUMMARY & CONCLUSIONS

Music has the ability to positively impact exercise performance, the research is both consistent and measurable, showing effects on behaviour and psychological states a like in a wide range of exercise participants. The evidence however is not all encompassing, there are still certain circumstances, tasks and participant groups that are more responsive to these benefits than others. However, there is a definitive role for music as a divergent stimulus in the exercise environment. Research in the area is still coming into fruition, fortunately we are now more aware of the inherent subjectivity of the stimulus and its complexities with regards to effects of a psychological, behavioural and physiological nature.

The current study focused on high tempo music (130bpm) and its effects on high-intensity cycling intervals. The present results demonstrated that this was an appropriate band of tempi to enhance exercise performance at maximal or near-maximal levels, and established that the participants were able to exercise for longer, while feeling better, working harder and recovering faster when they were listening to the music. The study also addressed a common debate amongst exercise physiologist, whether the causes of exercise induced fatigue are peripheral and metabolite-induced or central stemming from the central nervous system. All contractile properties (pre- and post-exercise) in this study showed a negative main effect for time, consistent with the hypothesis that high intensity aerobic exercise would have negative effects on muscular force production, but there was no condition effect with the music stimulus. Peripheral responses to fatigue such as metabolite accumulation, and tension are transmitted to the CNS by chemoreceptors, mechanoreceptors, type II and IV pain afferents and other afferent systems. While the music cannot directly modulate muscle contractile responses, the present results do suggest also that music seems to have a positive effect on the perception and voluntary response to these fatigue related stimuli. These discoveries provide further support for the idea that a physiological mechanism behind the beneficial effects of music use during exercise performance does exist. It is likely that this mechanism is related to the central nervous systems control over volitional fatigue at a level below consciousness; further still supporting the idea that exercise induced fatigue is not solely peripheral or metabolite induced.

The beneficial consequences of music use during exercise are associated with a plethora of interactions between elements of the musical stimulus itself and factors relating to the traits of the listener, aspects of the exercise environment, the task at hand, level of intensity and the wonderful cascade of psychological and physiological responses that accompany any exercise endeavour. However, the evidence presented in this study and the accompanying literature demonstrate that music is a valuable and effective divergent stimulus which consistently shows positive and measurable effects on the psychological state, behaviours and physiological responses of exercise participants. With these and future evidence based findings about the benefits of using music in the exercise environment hopefully we can help the general public to make exercise a more enjoyable and attractive pass time in an effort to increase lifelong exercise adherence for all and promote all benefits that go along with a healthy active lifestyle.

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