The Effect of Music on Tibial Accelerations in Recreationally Active Runners

Colin B. O'Leary

A thesis defense submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirement for the degree of Master of Arts in the Department of Exercise and Sport Science (Exercise Physiology).

Chapel Hill
2014

Approved by:

Anthony C. Hackney

Troy Blackburn

Barnett Frank

ABSTRACT

COLIN BURKE O'LEARY: The Effect of Music on Tibial Accelerations in Recreationally Active Runners
(Under the direction of Anthony Hackney)

The purpose of this study was to examine the effects of music on the peak tibial acceleration (PTA) and loading rate (LR) during running, along with other secondary physiological stresses. Thirty college-aged recreationally active subjects completed one continuous 30-minute treadmill bout at a self-selected intensity, with 15 minutes spent listening to music. The music order was counterbalanced. PTA, LR, heart rate (HR), rating of perceived exertion (RPE), and feeling score (FS) were assessed every 3 minutes. Salivary cortisol was assessed before, during, and post-exercise. There was no difference between music and no music conditions for PTA, LR, HR, RPE, or cortisol ($p>0.05$). FS was significantly greater when listening to music ($p<0.005$), indicating more enjoyment. In conclusion, listening to music increases feelings of wellbeing but is not enough of a distracting stimulus to alter the biomechanics or physiological stress of running, indicating no heightened risk of injury.

ACKNOWLEDGEMENTS

This project was made possible through the help of many people in the Exercise and Sport Science department. First, I would like to thank my advisor, Dr. Anthony Hackney, for his expertise and leadership. As this project evolved from a side research project to a full-blown Masters, he was there every step of the way advising me through the ups and downs of research process. I would also like to thank my committee members, Dr. Troy Blackburn and Mr. Barnett Frank. Without their expertise in sports medicine research this project would have never have gotten off the ground. I am especially grateful for the multiple members of the EXSS graduate students that helped with testing, including but not limited to Michelle Pebole, Joe Rosenberg, Amy Lane, Michael Scharville, Coleman Mills, and Liz Walz. I know all of you really enjoyed collecting the spit. Lastly, it goes without saying that the subjects are what made this project especially rewarding. Most of these students were some of the friendliest and helpful people I have met here at UNC – Chapel Hill.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

BASIS FOR STUDY

Introduction

Music and portable music players have become ubiquitous in the lives of most adolescents and young adults, as studies have found upwards of 90% of adolescents now listen to music using portable music devices (Vogel et al., 2009). In the exercise world, music is usually played using portable music players, such as iPods or other MP3 players. Additionally, there are now devices that play music and use technologies, like NikePlus, which also allow people to track their daily exercise routines (Besharat, 2010). This omnipresent ability to listen to music while exercising is thought to increase the adherence to exercise regimens (Annesi, 2001).

The benefits of listening to music while exercising are extensive and have been thoroughly reviewed (Karageorghis & Priest, 2012a; Karageorghis & Priest, 2012b). The use of asynchronous music, defined as music to which movements are not consciously synchronized, provides both psychological and ergogenic benefits during exercise (Karageorghis & Priest, 2012a). The effect of music is more pronounced in untrained exercisers (Brownley et al., 1995). Asynchronous music reduces ratings of perceived exertion (RPE) during low-to-moderate exercise (Nethery, 2002; Potteiger, Schroeder, & Goff, 2000; Szemdra & Bacharach, 1998). This reduction in RPE could be due to increased neuromuscular efficiency (Copeland & Franks, 1991), a diversion of attentional focus (Nethery, 2002), or an induction of a flow state, where the body is fully immersed in the activity (Karageorghis, Vlachopoulus, & Terry, 2000). The distraction effect of asynchronous music may also produce an ergogenic effect on the movement of exercise (Elliot et al., 2005).

Considering the possible neurological alterations that lead to increased physical work, endurance, and reductions in fatigue, the distraction effect of loud music might also affect the biomechanics of running. This distraction effect may change the biomechanics in a way that alters tibial accelerations, and therefore, the force of landing or ground reaction forces (GRFs). Listening to loud music may also make it difficult to hear one's footsteps. This also may cause a loss of control in regulating how hard the foot strikes the ground and force attenuation in the lower extremity. Only one study has examined GRFs in regards to music and exercise (Fujarczuk, 2006). Music increased the loading rate (LR) but not the maximal GRFs during the step aerobic exercise (Fujarczuk, 2006).

Tibial accelerometers have become more common in running biomechanics research and are lightweight, can measure multiple strides, be used during treadmill tasks, and are highly correlated to force platform derived data during running tasks (Sinclair et al., 2013). Both prospective (Davis et al., 2004) and retrospective (Milner et al., 2006) studies have found higher rates of stress fracture injuries in runners with greater tibial accelerations. Considering this link, research examining how music affects the biomechanics, especially during the stance and braking phases of running, is needed.

Purpose

1. In light of the aforementioned points, the purpose of this study was to examine the acute effects of asynchronous music on the peak tibial accelerations and time to peak accelerations produced during running.

2. A secondary purpose was to assess the acute effects of asynchronous music on cortisol, HR, RPE, and FS. These variables were used to assess whether music has a physiological and psychological effect.

Research hypotheses

1. Runners listening to music would have greater tibial accelerations and loading rates due to music's distracting effect, which decreases the attention paid to the existing feedback the body receives from the lower limbs concerning their biomechanics and force of impact.
2. Cortisol, HR, and FS are expected to be slightly augmented from listening to music, due to the chosen music's stimulatory effect, while RPE is expected to be attenuated due to music's distracting effect.

Definition of terms

1. *Asynchronous Music* – music used during exercise as a distracter, which is not consciously used to match to the movement of exercise
2. *Feeling Score (FS)* – An objective scale, related to the rating of perceived exertion scale, that assesses feelings of wellbeing during exercise.
3. *Ground Reaction Forces (GRFs)* – forces placed on the body during the contact phase of gait, specifically during foot strike.
4. *Loading Rate (LR)* – The rate of load being placed on the leg contacting the ground. Denoted as body weight (BW) per unit time from the major local minima before foot strike until peak tibial acceleration.

5. *Peak Tibial Acceleration (PTA)* – maximum acceleration occurring during the early stance phase of running, usually occurring within 50 ms of foot strike (Crowell & Davis, 2011)
6. *Rating of perceived exertion (RPE)* – An objective scale of feeling of exertion during exercise
7. *Synchronous Music* – music that is consciously used to match exercise movement to a specific beat or tempo
8. *Tempo* – The speed or pace of a given musical piece that is often expressed in beats per minute (bpm).

Delimitations

1. Subjects will be recreationally active young adults between the ages of 18 and 25 years who run three times per week in running for a total of less than 120 minutes at moderate intensity.
2. Subjects will arrive at the laboratory for each exercise trial after fasting for at least 2 hours.
3. Obese (BMI >30 kg/m^2) subjects, pregnant women, and subjects who have incurred a musculoskeletal injury in the last 6 months prior to participation will be excluded.
4. Subjects will only wear traditional (non-minimalist/barefoot) running shoes (i.e. Nikes, Brooks, Asics, etc.).

Limitations

1. The results can only be generalized to the sample.
2. The subject selection will be not truly random.

3. Subjects may not comply with the dietary and lifestyle guidelines set out before each exercise trial.
4. All subjects will listen to the same music playlist, which could be a non-preferred music choice, negatively affecting performance.

Significance of study

Sports injury is a major concern for the Center of Disease Control and Prevention and the general exercise population. If someone becomes injured, his or her adherence for completing exercise goals or routines is negatively affected. This loss of activity due to injury can result in detraining and weight increases from lack of activity. An inactive lifestyle could lead to other potential health problems, such as diabetes, loss of bone mineral density, and cardiovascular disease. These chronic diseases can place a large burden on the health care system. The use of music may increase adherence to exercise, as it distracts the listener from the discomfort of physical exertion. However, the possible changes in movement biomechanics due to listening to music while exercising has been scantly researched. Considering the ubiquitous use of music in the current iPod generation, establishing whether listening to music could heighten injury risk is important.

CHAPTER II

LITERATURE REVIEW

Introduction

This review will begin with what is currently known about the characteristics and use of music. The review will then transition into the effects of music on the performance, physiological, and psychological factors of exercise. The effect of music on many physiological and performance variables has been previously reviewed (Karageorghis & Priest, 2012a; Karageorghis & Priest, 2012a). This review will briefly mention the benefits of using music, but will mainly focus on the effect of music on physiological and psychological variables relating to rating of perceived exertion (RPE) and attentional feedback/awareness and how these factors could affect the biomechanics of running. Unless otherwise stated, this review will focus on the use of asynchronous music, or music that is not used to synchronize movements. The review will finish with a review of tibial acceleration and its relationship to both GRFs and its use for injury analysis and risk assessment.

Music

Use of Music

The invention of portable and lightweight MP3 players, such as iPods, has given runners the ability to listen to music anywhere and design individual playlists that improve performance (Curran, 2012). Studies have found upwards of 90% of adolescents listen to music using portable music devices (Vogel et al., 2009). Companies have begun to capitalize on the rise of music within the exercise domain. Runners can now download playlists from the web, which allow runners to tune their workouts with specific music characteristics. Cross branding between MP3 players, HR monitors, and GPS devices is also occurring. This gives runners even more control and perspective into their workouts (Besharat, 2010). Considering the ubiquitous use of music within the current culture, research on music and exercise is important for quantifying the effects of music for the individual.

Characteristics of Music

There are two types of music used in exercise settings, synchronous and asynchronous music (Karageorghis et al., 2007). Synchronous music is used during repetitive activities. It allows an athlete to consciously sync their movements to the rhythm of the music. On the other hand, asynchronous music is not used to consciously synchronize movements and acts more as a distracter. Mainstream music, such as music played on the radio, would be considered asynchronous music and is the type predominantly used in research.

Asynchronous music is composed of four factors that contribute motivational qualities to an athlete (Karageorghis et al., 2012a). Rhythm response refers to the effects of musical rhythm, especially tempo (speed of the music in beats per minute). Musicality refers to the pitch-related elements of music such as harmony and melody. Cultural impact concerns the popularity and occurrence of the music within society or a sub-cultural group. Lastly, association refers to the extra-musical associations that may be evoked, such as with Eye of the Tiger by Survivor and running up the steps of Philadelphia Museum of Art. Rhythm response and musicality are the internal factors of music, while cultural impact and association are the external factors (Figure 1).

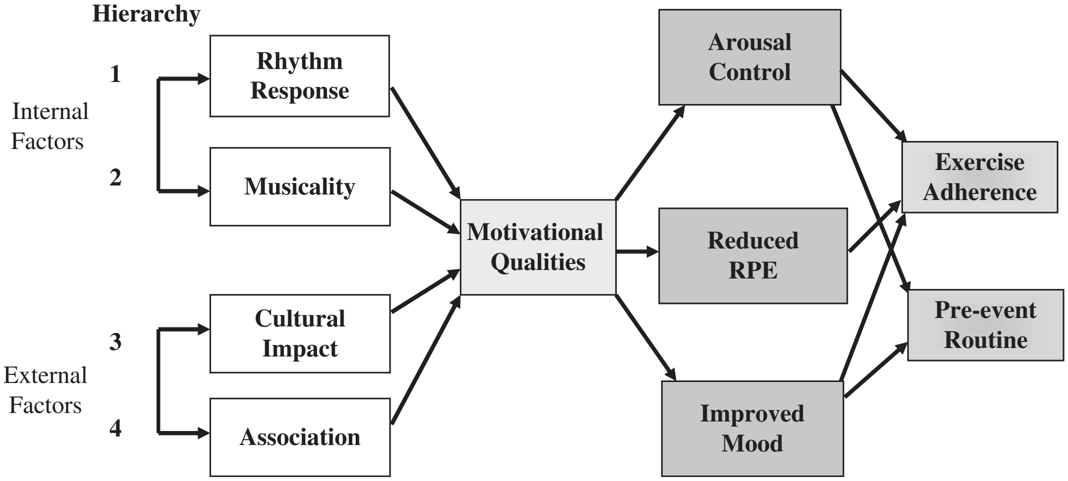


Figure 1: Conceptual framework of asynchronous music and exercise. (Adapted from Karageorghis et al., 2012a)

Tempo is considered the most important factor in determining an individual's response to music (Holbrook & Anand, 1990). There is a preference for faster tempo music, due to the increases in physiological arousal with this type of music (Karageorghis, Jones, & Stuart, 2007). Fast music of a high intensity or volume is the most appropriate for moderate exercise, as it helps propel the exerciser (Edworthy & Waring, 2006). Slower tempo music appears to be the least preferred tempo when comparing fast, moderate, and slow tempo at moderate intensities (Karageorghis, Jones, & Low, 2006). The recommendation for tempo is a beats per minute rate between 125-140 (Karageorghis et al., 2012).

A recent article published by experts in the field of music and exercise has recommended other specific qualities for asynchronous music (Karageorghis et al., 2012). These suggestions include: music that is familiar to the listener, reflective of his or her personal preferences, and motivational. The musical selection should include prominent rhythmic qualities, along with melodic and harmonic structures adequate for repetitive tasks such as running. The lyrics of the music should also contain motivational statements. By following the above recommendations, exercisers can benefit from the effects of music. By following these recommendations, future researchers will be able to compare their results to previous studies using music.

Effect of Music on Performance and Physiological Variables

The effects of asynchronous music on enhancing performance have been well reviewed (Karageorghis & Priest, 2012a). Music elicits an improvement in exercise performance by either delaying fatigue or increasing work capacity. This effect results in elevated levels of endurance, power, productivity, or strength (Karageorghis & Priest, 2012a). Music results in an increase in self-selected intensity (Abraham & Thomas, 1999). Subjects can also exercise for longer periods before exhaustion while listening to music (Bharani et al., 2004; Copeland & Franks, 1991; Elliot et al., 2004). These studies were both running and cycling tasks with different types of music, suggesting the effects of music are not limited to specific conditions.

Music can also lower heart rate and blood pressure (Ghaderi, Rahimi, & Azarbajyjani, 2009; Szmedra and Bacharach, 1998). Both studies suggested that music allowed the subjects to relax, which increased their blood flow and muscle recovery. However, measures of blow flow or muscle recovery measures were not evaluated in either study. Other studies have examined the possibility of heart rate syncing to the tempo or beat of the music (Karageorghis & Priest, 2012a). But there does not seem to be any relationship between music tempo and heart rate.

Yet these ergogenic effects of music are not evident in all studies examining music and exercise (Annesi, 2001; Pujol & Langenfeld, 1999). Also, most of the benefits of music are only apparent at low-to-moderate exercise intensities. Listening to music during maximal efforts does not exhibit any differences between conditions (Boutcher et al., 1990; Tenenbaum et al., 2004).

The effects of music also seem to vary due to the training status of the exerciser. Studies support music as being more beneficial for untrained individuals compared to trained athletes (Brownley, McMurray, & Hackney, 1995; Mohammadzadeh, Tertibiyan, & Ahmadi, 2008). At both low- and high-intensity conditions, untrained subjects experience a larger increase in positive feeling states in response to stimulative music during exercise and into recovery. Stimulative music may actually be detrimental to trained individuals at high intensities (Brownley et al., 1995). Trained individuals may focus more on the running and the specifics of the motion, which asynchronous music can disrupt.

Effect of Music on Cortisol

Little research has examined the effects of music on cortisol (Brownley, et al., 1995; Ghaderi et al., 2009). Brownley et al., (1995) found a slight increase in plasma cortisol after listening to fast music compared to sedative music and no music at high intensities. Yet these differences ($p<0.07$) did not reach the statistical significance established a priori ($\alpha<0.01$). This study also used a discontinuous walk/run protocol, which could affect the release of cortisol compared to a single continuous bout. Ghaderi and colleagues (2009) examined salivary cortisol in response to a submaximal exercise bout to exhaustion performed at 80-85% maximal heart rate. The use of salivary cortisol is an excellent predictor of free plasma cortisol (Laudet et al., 1988). An augmented cortisol response occurred immediately post-exercise in both the motivational and no music conditions compared to the relaxation music ($p<0.01$). Listening to relaxing music produced a smaller cortisol response compared to no music at 30 minutes post-exercise ($p<0.05$). Relaxing music was not different from motivational music at 30 minutes post-exercise. Yet, it is important to note that the motivational group's running time was 41.7% longer than the relaxation group ($p<0.01$). Since the duration of exercise affects cortisol release, the differences might simply be an effect of exercise duration. This study also utilized a between group music design, which could confound the results due to the subjects' previous training history and diet. Considering the lack of agreement in the literature, the current study will include an exploratory analysis of cortisol, using salivary measurement techniques to allow for easier sampling and a continuous protocol. The protocol in the current study will also have a set running duration and use a repeated measures design.

Effect on Rating of Perceived Exertion

Multiple studies have exhibited 10% reductions in RPE when exercising with music compared to control conditions (Bharani et al., 2004; Nethery, 2002; Potteiger et al., 2000; Szmedra & Bacharach, 1998). Most suggest a dissociation or distraction effect of music leads to this improved physiological functioning during exercise. Along with reductions in RPE, music has positive effects on enjoyment of exercise, even when working at a higher work rate (Miller et al., 2010; Elliot et al., 2004). However, much like with the other physiological variables, there is less of an effect on RPE at higher exercise intensities (Tenenbaum et al., 2004).

There may be a relationship between the effects of music on RPE and work output, as music enhanced work output with no increases in RPE (Edworthy & Waring 2006; Elliot, Carr, & Orme, 2005). This suggests music may motivate individuals without them being consciously aware of the greater workload. Increases in workload are sometimes even accompanied by decreases in RPE while listening to music (Elliot, Carr, & Savage, 2004).

The differences in RPE between these studies could be due to the differences in musical selection or the type and intensity of exercise. But these studies suggest music may motivate individuals without them being consciously aware of the greater workload.

This reduction in RPE and increase in enjoyment add to the chance that people exercising with music will more likely adhere to regular exercise (Annesi, 2001). Considering the rise of obesity, metabolic, and cardiovascular diseases in the United States (Ogden et al., 2012), this increased adherence due to music could be important for the current health crisis.

Effect on Attentional Focus

Many of the benefits of music result from reductions in RPE, which allow individuals to work harder or longer compared to without music. These reductions in RPE could be due to: a diversion of attentional focus, control of arousal, evocation of other cognitive processes or moods and emotions, induction of flow states, and encouragement of rhythmic movement (Karageorghis, Vlachopoulus & Terry, 2000; Nethery, 2002; Priest & Karageorghis, 2008; Rejeski, 1985). Of these, the diversion of attentional focus or dissociation effect appears to be the predominate hypothesis why music affects exercise performance (Nethery, 2002; Nethery, Harmer, & Taaffe, 1991; Rejeski, 1985). Rejeski's (1985) seminal paper gives insight into a parallel processing conceptual model that explains how music affects attentional focus and RPE. According to Rejeski, only a limited amount of information can be processed at a given time. One overriding stimulus may be able to prevent the processing of other stimuli outside of the attention span. Therefore, musical stimuli may block the transmission of the internal sensations associated with exercise, like fatigue. This model suggests that at a lesser exercise intensity, physiological cues of effort are less pronounced and psychological cues affected by music will influence RPE. However, when individuals are working at near maximal aerobic capacity, physiological cues will predominate and have a greater influence than music on RPE. This suggests music can occupy an individual's attention and generate positive feelings, reducing RPE at lower intensities.

Nethery and colleagues (1991) added to this model by suggesting that the cognitive processing of sensations is heightened by the capacity of the central nervous system to transfer sensory information from perception to the level of the consciousness. This means that a limited channel capacity, such as when an individual is listening to music and running, affects bringing a sensation into full awareness, such as fatigue. Others have suggested that as a task becomes more complex and novel, signals involved with effort would be preferentially processed, which reinforces the notion that at higher exercise intensities music will have less of an effect (Pennebaker & Lightner, 1980).

This effect on attentional focus can also lead to a state of body and mind described as a flow state (Karageorghis et al., 2007). This state can be explained as the total absorption into an activity, to the point were time appears to either speed up or slow down. This state leads to a state of awareness where the mind and body act together to complete a task, with very little regard for signals from the sensory. Results of past work indicate that music can have a positive impact on the development of the flow state if it can affect an individual's attentional focus (Pates et al., 2003).

Music has been described in numerous publications as being an effective distracter, reducing RPE and cues from fatigue (Nethery, 2002; Karageorghis & Priest, 2012a; Potteiger et al., 2000). This allows for attentional focus to be directed towards external sources (i.e. music) rather than lingering on the discomfort and fatigue being experienced. However, non-preferred music can have the opposite effect and should be avoided, as it can shift the focus to internal sources increasing RPE (Nakamura et al., 2010; Tenenbaum et al., 2004). This study will use currently popular music, and may also use the degree of preference of the chosen music as a covariate to help mitigate the possibility of the music condition being affected by negative feelings.

Music and Biomechanics

Multitudes of research have been published concerning the effect of music on performance, physiological, and psychological factors. Yet little research has examined the effects of music on biomechanics. In one of the few music and biomechanics papers, music altered stride interval dynamics, as overground walking with music led to more deviations in stride interval time series compared to overground walking without music (Sejdic et al., 2012). Participants reported that the music caused them to lose concentration at times during the task. This could be due to the increased amount of external distracting cues from the music, which is in line with Rejeski's parallel-processing model (1985). Music can also increase walking speeds and induce synchronization of walking pace to the beat of the music (Styns et al., 2007). Other studies suggest music induces a rhythmic auditory stimulation, which affects the motor system through the auditory rhythm or tempo or music, changing an individual's walking gait (Prassas et al., 1997).

Yet, no study has examined the effects of music on running biomechanics, even though most of the music and exercise studies use running. Theoretically, music could affect the biomechanics of running considering the distracting effect of music and its ability to limit internal signals. Some research suggests music may cause an improvement in the control (Prassas et al., 1997) and neuromuscular efficiency (Yamashita et al., 2006) of the running motion. However, considering Sejdic et al.'s (2012) results concerning an increase in nonstationary walking, music may alter running gait. Listening to music could lead to an increase in injury risk from the lack of perception from internal cues, such as from fatiguing muscles, muscle spindles, and golgi tendon organs. Overtime, these slight changes may become problematic, as an exerciser continues to ignore these essential physiological cues. Research has also not taken into account that it is hard to hear when the foot strikes the ground when listening to music, possibly altering the contact phase of gait. Future research is needed to establish if music affects the biomechanics of running, especially the forces of the contact phase of gait.

Tibial Acceleration

Relationship with Ground Reaction Forces

The gold standard for ground force identification during running is derived from force platform data. However, the use of force platforms is usually confined to specific sport or gait laboratories. Force platforms also restrict the number of analyzed consecutive gaits cycles due to the limited size and number of platforms. The use of force platforms may also distort a runner's natural gait, as the runner must fully contact the platform during each trial to achieve a full assessment of the foot contact and forces involved with it.

Therefore, researchers have explored other methods to quantify the characteristics of foot strike impacts during more activity-specific tasks. This search has given rise to the use of accelerometers (LaFortune, Hennig, & Valiant, 1995). Accelerometers are lightweight, reduce potential gait alterations due to force platform targeting, and can record data for multiple strides (Sinclair et al., 2013). This makes them effective devices for analyzing gait in both laboratories and more applied field-based settings. Accelerometers placed on the tibia can quantify the shock attenuated during fatigued running (Mercer et al., 2003; Mizrahi et al., 1997) and examine both the prospective and retrospective risk of stress fractures (Davis et al., 2004; Milner et al., 2006). Tibial accelerometers do not need to be bone-mounted to attain accurate results, as skin-mounted accelerometers are just as effective (LaFortune, Hennig, & Valiant 1995). Using accelerometers placed on the tibia may be advantageous for estimating GRFs since the accelerometer can be placed close to the foot and does not inhibit the natural stride of the runner.

Considering the prevalence of information coming from GRFs, but the less applied nature of force platforms, it is important to assess if tibial accelerometers can be used in place of force platforms. Yet, few studies have examined the relationship between tibial acceleration and GRFs (Elvin et al., 2007; Sinclair et al., 2013).

Sinclair and colleagues (2013) compared gait data from tibial accelerometers and force platforms during a running task. They found a strong correlation ($r^2 = 0.92$) between the duration of the stance phase when comparing the two methodologies using five subjects. This suggests that gait events can be reliably and accurately detected using a tibial accelerometer. However, the authors caution the use of accelerometers, stressing the proper mounting of the device, as the mounting and position can influence the signal (Sinclair et al., 2013). This study also only compared the time of the gait events and did not try to compare the quantified accelerations to the GRFs from the force platform.

Elvin and colleagues (2007) examined the relationship between peak GRF and peak tibial acceleration for landing after vertical jumping. There was a strong relationship ($r^2 = 0.81$) between the peak GRF and peak tibial accelerations during landing from a vertical jump using six subjects. This suggests tibial accelerometers could quantify the forces from a landing task like running. However, further research is still needed examining the specific relationship between GRFs and tibial accelerations during running, especially over a large number of discrete events (i.e. foot strikes).

Running Injuries

During running, the body experiences vertical forces about 2.5 times body weight. Most repetitive injuries, such as stress fractures, are due to the total load placed upon the tissue. This makes assessing biomechanics important for quantifying the risk of stress fractures and other repetitive loading running injuries. Stress fractures are among the five most common injuries, accounting for 50% of all injuries sustained by runners (McBryde, 1984). The tibia is the most common site of stress fractures in runners (Matheson et al., 1987). Stress fractures force runners to refrain from running and other impact related activities for up to 8 weeks (Beck, 1998). This can lead to large decrements in cardiovascular and muscular function and performance (Coyle et al., 1985). Reoccurrence rates for developing another stress fracture are also high, at upwards of 36% (Hauret et al., 2001). This makes the assessment of possible risk factors, particularly through field-based methods such as tibial accelerometers, important for injury prevention.

Intrinsic running biomechanics is a risk factor for stress fractures when analyzed using tibial acceleration data (Davis et al., 2004; Milner et al., 2006). A prospective study found runners with a tibial stress fracture exhibited greater lower extremity loading, including greater tibial shock, and higher instantaneous and average vertical LRs before injury (Davis et al., 2004). In a retrospective study, runners with a history of tibial stress fractures exhibited greater instantaneous and average vertical LRs, but no difference in LRs during braking. Peak positive acceleration was also greater in the stress fracture group

(Milner et al., 2006). Considering music might affect running biomechanics, music could potentially affect the risk of developing a stress fracture due to changes in biomechanics. Another possible mechanism for stress fracture injury is fatigue (Mercer et al., 2003; Mizrahi et al., 1997). Fatigue reduces shock attenuation, or the process of absorbing impact energy (Mercer et al., 2003; Mizrahi et al., 1997). Specifically, long distance running involves a gradual increase in the impact loading on the lower legs during a run (Mizrahi et al., 2000). Bone overuse injuries are related to fatiguing muscles due to either a loss of shock-absorbing capacity of muscle or because of compensations in movement patterns due to the change in muscle ability (Mercer et al., 2003). The poor shock attenuation in the leg will increase the attenuation demands placed on the knee and hip joints, leading to further injuries. Since music enhances submaximal performance by allowing someone to exercise longer and harder, listening to music could lead to greater muscular fatigue. This could be unbeknownst to the runner due to lessened attentional feedback (from the music), resulting in a repetitive loading injury.

Summary

The rise of cheap, portable, and lightweight music players in exercise settings has given way to many studies concerning the effects of music on physiological, psychological, and performance variables. The characteristics of the music, such as the tempo, harmony, lyrics, and personal preference, do play some role in the alleged benefits, as non-preferred music can eliminate any these benefits. Music reduces RPE at low to moderate intensities, with untrained subjects responding to music more than trained individuals. Decreases in RPE can be explained by how music modifies the attentional focus or feedback away from the sensory, where individuals would perceive discomfort and fatigue. Yet, if music produces the desired effect, it is reasonable to believe it might change how an individual moves during exercise, since he or she cannot perceive all of his or her sensations due to music blocking these pathways. Overtime, slight changes in movement or gait can lead to injury. Therefore, the effect of music on running biomechanics needs to be further investigated.

CHAPTER III

METHODOLOGY

This study required each subject to make one laboratory visit. The visit consisted of an orientation, physical screening, and the treadmill running testing. The treadmill testing consisted of 30 minutes of running at a self-selected speed. Subjects wore in-ear headphones during the entire duration of the study but only listened to music during 15 minutes of the trial. Tibial accelerations were assessed to characterize the changes in biomechanics.

Subjects

Subjects were males and females ages 18-24 years recruited from academic and physical activity classes, and at UNC-Chapel Hill's fitness facilities. Subjects were healthy, of normal body weight, and classified as recreationally active runners if they participated in less than or equal to three times per week of running for a total of no more than 120 minutes at moderate intensity and used music consistently. Current training levels were documented via self-report. Subjects had not drastically changed their exercise regimens in the last 6 months. All subjects were free of acute or chronic illnesses and had no musculoskeletal injuries in any limb within the 6 months prior to participation. Subjects with a body mass index (BMI) of ≥ 30 kg/m^2 were excluded from the study, which was assessed during the initial screening. Other exclusion criteria included: use of minimalist running shoes, a recent history of any major musculoskeletal injury, mental illness, or chronic non-steroidal anti-inflammatory (NSAID) drug use.

Protocol

Each subject reported to the Applied Physiology Laboratory at UNC – Chapel Hill on one occasion wearing the appropriate athletic clothing and conventional (non-minimalist or non-'barefoot') running shoes. The beginning of the testing session was used to obtain written consent, fill out a medical history form (Appendix D) and Physical Activity Readiness Questionnaire (PAR-Q) (Appendix E), and familiarize subjects with the testing procedures. If the subject meets the inclusion criteria, then the testing session included the experimental procedure. Subjects were asked to refrain from strenuous exercise, caffeine, and alcohol at least 24 hours before the testing session. Subjects were also asked to eat a balanced diet 24 hours before the test and be 3-4 hours post-prandial and well hydrated before the treadmill test.

Music Selection

Music was selected based on the guidelines set out by Karageorghis et al., 2012, including music within the tempo band of ~125-140 beats per minute and consisting of prominent rhythmic qualities. Each subject listened to the same music in the same order at the same volume level. This standardization does not take into account personal preferences of music choice, but the music selection (recent top 40 pop music) should be at least moderately familiar to the listener (Karageorghis et al., 2012). Music that matches the aforementioned criteria has been found to affect an individual's performance and psychological state while exercising (Karageorghis et al., 2012). The music tracks used in the study can be found in Appendix B. Subjects were asked if they currently use music when they exercise and were asked post-test if they enjoyed the music selection using a standard five-point Likert scale.

Treadmill Running

The exercise session was conducted on a standard (non-instrumented) Quinton MODEL Q65 treadmill (Cardiac Science Corporation, Bothell, WA). Before beginning the treadmill running session, subjects' height (Stadiometer, Perspective Enterprises, Portage, MI, USA) and weight (Mechanical scale, Detecto, Webb City, MD, USA) were recorded. Subjects were also fitted with a Polar heart rate monitor (Polar Electro Inc., Lake Success, NY) that they wore throughout the test. Resting heart rate (HR) was assessed after 10 minutes of seated rest.

Subjects were asked to run on the treadmill for 30 minutes at a self-selected pace they would use for a normal run. They were asked to consider and choose their speed before they came into the laboratory and were asked again during the 10 minute seated rest. The subject began the session with a 5-minute jogging and stretching warm up. The speed selected for testing was submaximal in nature and represented a level that was comfortable enough for the subject to talk with the investigator throughout the trial. Subjects ran for 30 minutes at this speed with the grade remaining constant at 0% for the entire session. Heart rate, Feeling Score (FS), and RPE using the 6-20 point scale (Borg, 1970) were monitored every 3 minutes. The FS is an 11-point scale raining from +5 (feeling very good) to -5 (feeling very bad) (Hardy & Rejeski, 1989) used in previous research concerning music and running (Brownley et al., 1995; Elliot et al., 2005). Subjects were provided with a portable music device (iPod Shuffle, Apple, Cupertino, CA) and in-ear headphones (Apple, Cupertino, CA) at the beginning of the running trial. Subjects wore the headphones for the entire duration of the trial, but ran for 15 minutes with music and 15 minutes without music with the order of the music/no music conditions being counterbalanced. In the no music condition, the subjects ran without any potentially distracting visual or auditory stimuli. Subjects were allowed to drink water *ad libitum* throughout the treadmill protocol.

After completion of the 30-minute treadmill run, the treadmill was slowed and the subjects were allowed to cool down at a walk for 3-5 minutes. Once the subjects sufficiently cooled down (HR <100 bpm), they were allowed to leave the laboratory.

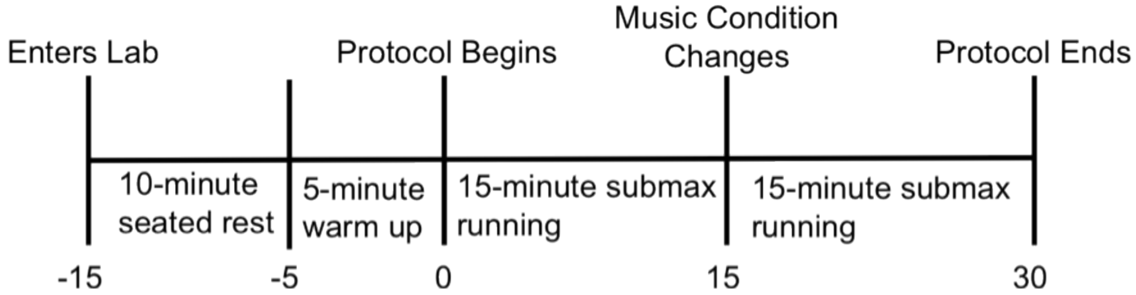


Figure 2: Exercise protocol overview

Tibial Acceleration Assessment

Before the exercise session began, subjects were fitted with a lightweight tri-axial accelerometer (model 356A32, measurement range: ± 50 *g*, mass: 5.4 gram, PCB Piezotronics, Inc., Depew, NY, USA), which was worn during the entirety of the running session. One of the accelerometer axes was aligned with the long axis of the subject's tibia and securely pre-wrapped and taped to the anteriomedial aspect of the proximal tibia (Flynn et al., 2004; Mizrahi et al., 2000) (Figure 3). The acceleration of the tibia was used to characterize the impact between the subject's foot and the ground.

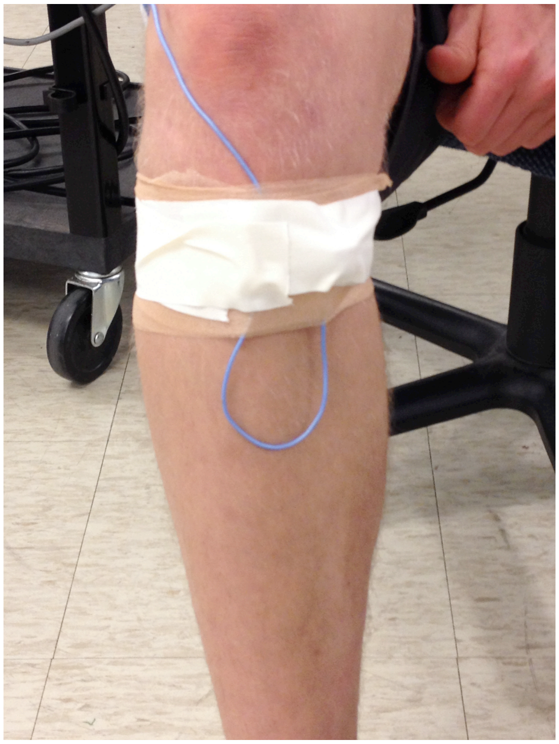
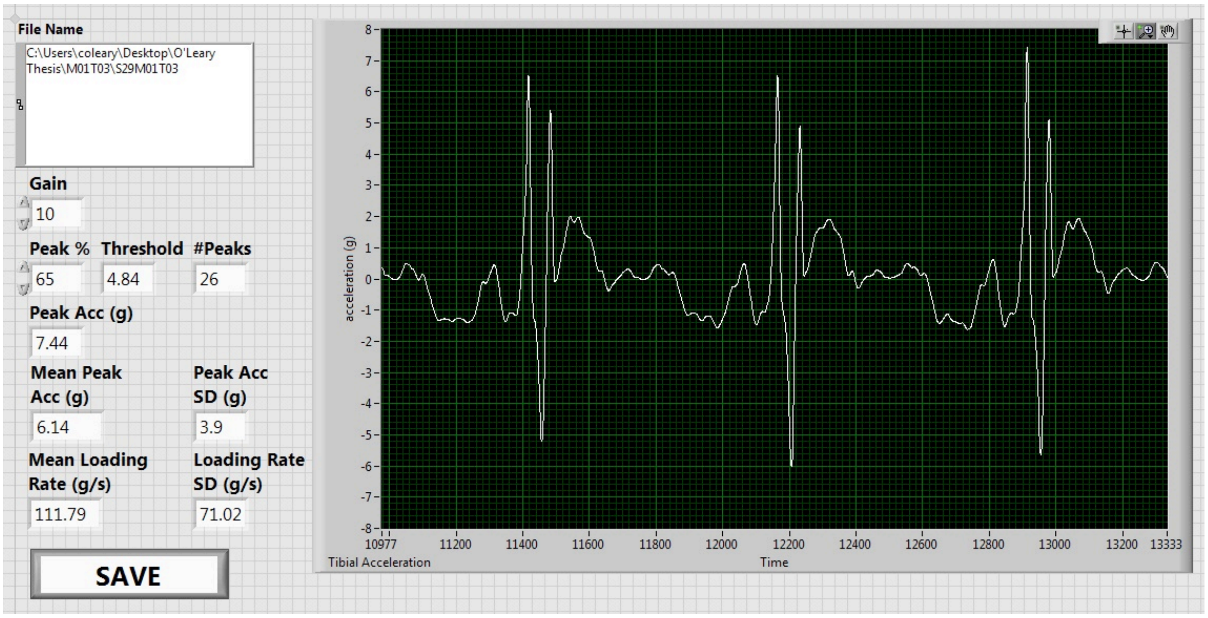


Figure 3: Experimental set up for tibial accelerometer

During the trial, tibial accelerations were assessed every 3 minutes for 20 seconds. Accelerations were sampled at 1000 Hz via the tri-axial accelerometer. The acceleration signal was filtered using a 75 Hz 2nd-order zero-phase-lag Butterworth lowpass filter to attenuate the component of the signal attributable to tissue artifact and resonance. Peak tibial acceleration (PTA) (Body Weight - BW) was determined as the highest acceleration (g) during the initial contact phase of gait and converted to BW using mass and acceleration due to gravity. Initial contact was established by finding the peak and backtracking 125 milliseconds to the find the minimum value and its corresponding timepoint. Loading rate (BW/s) was determined as the change in g's from the local minima to the PTA of each foot strike per unit time and converted to BW/s. A Labview software batch-processing program (National Instruments, Austin, TX) was written to analyze each peak that fell within 65% of the greatest peak during each 20-second epoch. To reduce the selection of peaks that did not represent foot strikes, no peak could be selected within the 200-millisecond timeframe after the first peak was selected. The average PTA and LR for the five 20-second segments for each condition per subject were then averaged together, taking in account the number of peaks per trial, to generate a grand mean for both the music and no music conditions. If there were less than ten peaks during one of the epochs, due to large outliers, then that epoch was discarded and only four 20-second epochs were used for analysis.



File Name: C:\Users\coleary\Desktop\O'Leary Thesis\M01T03\S29M01T03
Gain: 10
Peak %: 65
Threshold: 4.84
#Peaks: 26
Peak Acc (g): 7.44
Mean Peak Acc (g): 6.14
Peak Acc SD (g): 3.9
Mean Loading Rate (g/s): 111.79
Loading Rate SD (g/s): 71.02

Figure 4: Screenshot of Labview batch-processing program used to analyze tibial accelerometer data. Screenshot is zoomed in to show three individual peaks.

Salivary Cortisol Sampling

As part of a preliminary investigation of the effects of music on biochemical factors, salivary cortisol was assessed during the treadmill test. Salivary cortisol was sampled pre-exercise after the 10 minute seated rest, after the first 15 minutes of running, and at the end of the treadmill test at 30 minutes. To collect the saliva samples, subjects rinsed their mouths with water, spit, and then allowed saliva to accumulate in their mouths. If saliva secretion needed to be stimulated, subjects were asked to chew on paraffin film. A minimum of 0.5 mL of saliva was collected into a polypropylene cup for each sample. Collected saliva samples were transferred into cryo-freeze tubes and stored at -80° Celsius for later analysis.

Saliva cortisol levels were assessed using an expanded range high sensitivity enzyme immunoassay (ELISA) kit (Salimetrics, State College, PA). Saliva specimens were assayed using a pooled means method. Each individual sample was centrifuged and then 20 µl of each sample was pipetted into one comprehensive tube for each sample condition. Therefore, there were six pooled mean tubes (M1-Pre, -Mid, -Post; M2-Pre, -Mid, -Post). Each pooled mean tube was assayed in quintuplicate. Six individual subjects that were either responders or non-responders were also assayed in the same ELISA.

Statistical Analysis

All statistical analyses were performed using SPSS statistical software (version 19.0, Chicago, IL). Significance was set a priori at $\alpha<0.05$. All values are displayed as means ± standard deviations (SD), unless otherwise noted. After using appropriate sample size calculation software, it was determined that at least 20 subjects were needed for statistical significance at a power level (ß) of 0.80 and α level of 0.05 (Appendix A).

To determine if there was a significant difference in PTA and LR during the different conditions (music or no music) separate dependent t-tests were used. Before running the dependent t-tests on the separate music inductions, other dependent t-tests were used to confirm that there were no differences in the first and last epochs for each condition (ie 3 and 15 minute timepoints). Dependent t-tests were also used to determine differences in mean HR, RPE, and FS during the different conditions (music or no music). Salivary cortisol was analyzed using a 2x3 (group: music-first and music-second x time: pre-, mid-, and post-exercise) weight means repeated measures ANOVA.

CHAPTER IV

RESULTS

Subject Characteristics

Thirty volunteers (23 women, 7 men, 167.0 ± 8.6 cm, 59.8 ± 9.6 kg), ages 18-24 (19 ± 1 y) participated in the study. Subjects were untrained (less than 120 minutes/week) for at least the six months prior to participation, but were recreationally active in nature (90 ± 24 min/week of aerobic exercise). Subjects ran at self-selected comfortable pace (9.8 ± 1.0 km/h) during the trial, which elicited an exercise intensity of 79.2% ± 11.0% based on the Karvonen HR reserve equation (Karvonen & Vuorimaa, 1988). They also found the music to be enjoyable (4.2 ± 0.5 on 5 point Likert scale, with 5 being 'enjoyed a lot' and 1 being 'did not enjoy at all').

Tibial Acceleration

Table 1 exhibits mean ± SD of PTA, LR, and number of peaks per 20-second epoch. There was no difference between the two music conditions for PTA (p=0.76), LR (p=0.41), or number of peaks (p=0.29).

Table 1: Tibial acceleration measurements during 30-minute exercise session with 15 minutes spent both with and without music (mean ± SD)

Measure	Music	No Music
PTA (BW)	0.62 ± 0.23	0.61 ± 0.22
LR (BW/s)	16.37 ± 8.30	15.84 ± 6.25
Number of peaks	23.0 ± 4.7	22.6 ± 5.4

n=30; SD = standard deviation, PTA = peak tibial acceleration,
LR = Loading Rate

Physiological and Psychological Response

Table 2 exhibits mean ± SD HR, RPE, and FS responses. The only difference between music and no music conditions was a greater FS during the music condition ($p<0.005$). Neither HR ($p=0.88$) nor RPE ($p=0.67$) were different between the music and no music conditions.

Table 2: Effects of music on physiological and psychological responses (mean ± SD)

Measure	Music	No Music
Rating of Perceived Exertion (RPE)	12.0 ± 0.9	12.0 ± 0.9
Feeling Score (FS)	2.1 ± 1.2*	1.6 ± 1.3
HR (bpm)	176 ± 14	176 ± 14

*$p<0.005$; n=30; SD = standard deviation, HR = heart rate,
bpm = heart beats per minute

Salivary Cortisol

Figure 5 exhibits the cortisol response to the 30-minute treadmill session via the pooled mean samples (raw data in Appendix G). A 2 x 3 repeated measures ANOVA found no difference between any of the means ($p=0.76$).

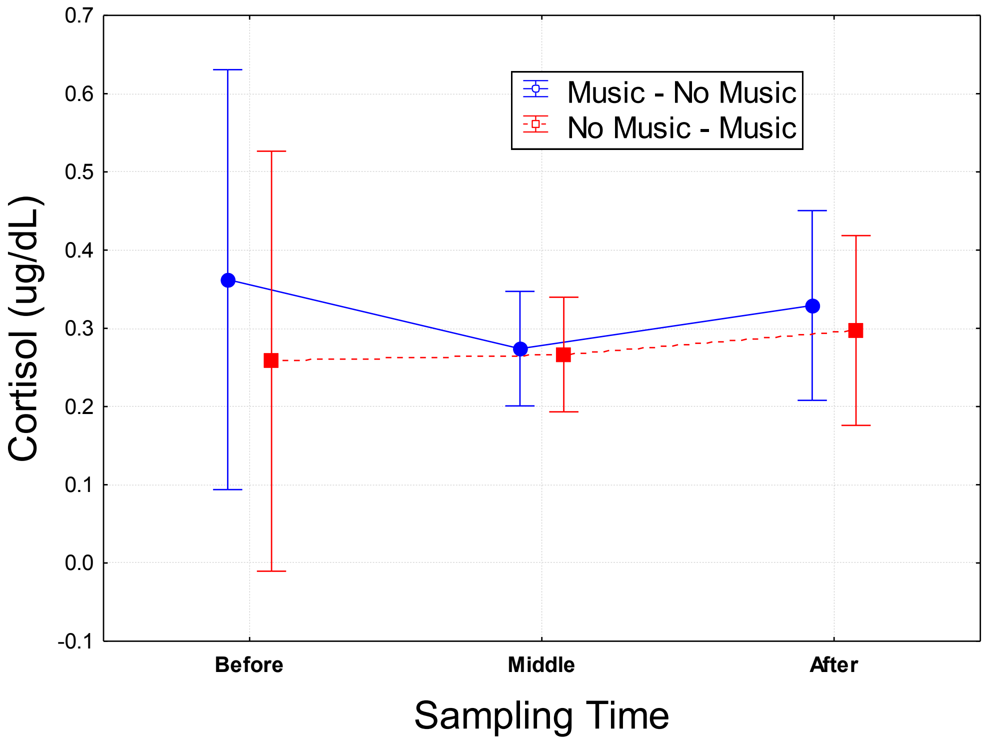


Figure 5: Effects of music condition and time on cortisol secretion (Mean ± CI)

CHAPTER V

DISCUSSION

Introduction

The primary purpose of this study was to examine the acute effects of asynchronous music on PTA and LR produced during a 30-minute bout of submaximal treadmill running. It was hypothesized that runners listening to music would be associated with greater PTA and LR due to the distracting effect of music, which decreases the attention paid to the existing feedback received by the central nervous system. A secondary purpose of this study was to assess if music had physiological and psychological effects on the subject through the monitoring of salivary cortisol, HR, RPE and FS. Cortisol, HR, and FS were hypothesized to be slightly augmented when listening to music, due to the chosen music's stimulatory effect. RPE was hypothesized to be attenuated due to music's distracting and uplifting effect.

The discussion is divided into several sections, based on the variable being examined. The discussion begins with an examination of the tibial accelerometer data, as this was the main purpose of this study. The next section contains HR, RPE, and FS, as these variables have been commonly studied in conjuncture with regards to music. The final section evaluates salivary cortisol. The section for each variable has subsections on the comparison of the findings to previous studies, along with physiological reasoning for the results found in the current study. In some cases, directions for future research are also mentioned within each variable's section. Finally, limitations and conclusions of the present study are presented.

Tibial Acceleration Response

Examining the effect of listening to music on tibial acceleration was the primary purpose of this study. It was hypothesized that PTA and LR would be augmented during the music condition, as the listener would be distracted by the music and also be unable to hear his or her foot strikes. However, the results of this study do not support the initial hypothesis, as both PTA and LR were not different between music and no music conditions.

No previous research was found that examined the effects of music on biomechanics during a running task. However, some studies have examined the effects of music on LR and gait during physical activity (Fujarcuk, 2006; Sejdic et al., 2012; Styns et al., 2007) or examined PTA and LR during treadmill running (Crowell & Davis, 2011; Mercer et al., 2003; Schaffner et al., 2005). Fujarczuk (2006) examined the effect of different music tempos on GRFs and LRs during step aerobics. The tempo of the music affected LR, with greater LRs being evident at faster music tempos around 138 BPM. Unfortunately, the study by Fujarczuk (2006) did not include a no music condition, as all groups listened to some form of music. In the current study, all the songs had similar tempos, ranging from 126-136 (Appendix B), and the effects of different tempos was not analyzed. Considering Fujarczuk's study (2006) exhibited differences in LR at higher tempos, it could be hypothesized that the presence of fast music could affect LR compared to having no music. However, this was not supported by the results of the current study, as LR was not different between music conditions.

The LRs in the current study were much higher compared to the LRs in Fujarczuk's study (2006). Yet, this could be due to the different tasks performed in the studies (running vs. stepping). Other studies reported LRs near 40 BW/s for treadmill running at 11.26 km/h using force platforms (Schaffner et al., 2005). These LRs are also not like the LRs reported in the current study. The differences could be due to the use of force platforms, rather than accelerometers. Research has shown there is a relationship between data derived from accelerometers and force platforms (r = .76-.96) (Hennig & LaFortune, 1991; Sinclair et al., 2013). Yet this relationship is not perfect and should be interpreted cautiously.

Other studies have examined PTA and LR in regards to treadmill running using tibial accelerometers (Crowell & Davis, 2011; Mercer et al., 2003; Shung, Oliveria, & Nadal, 2009). The PTA in the current study, when converted to g's, was within the SD of the PTA reported in other studies (Crowell & Davis, 2011; Mercer et al., 2003; Shung et al., 2009). However, the LRs were not similar between our study and Shung et al.'s (2009), as their results demonstrated LRs about two times greater than the current study. Both Crowell and Davis (2011) and Mercer et al. (2003) used somewhat similar tibial acceleration methods to the current study. However, they placed their accelerometer on the distal tibia, closer to the ankle joint, which could have produced different results. The current study used a proximal tibial placement because of safety and reproducibility reasons, as none of the subjects had worn an accelerometer. The researchers did not want tripping to be an issue or for subjects to worry about the accelerometer impeding their natural gait. The plastic mount for the accelerometer was also fitted for a wider surface, which made the proximal tibia a more suitable location. Future research should examine if there is any difference between the locations of tibial accelerometer placement, as LRs derived from accelerometers may be dependent on accelerometer placement.

Other research has examined the effects of music on gait in a healthy population (Sejdic et al., 2012; Styns et al., 2007). Sejdic and colleagues (2012) stated that music alters stride interval dynamics, as music led to a more nonstationary stride interval time series. The researchers surmised that gait is susceptible to the rhythmic sensory cuing (tempo/beat) of music. Likewise, Styns and colleagues (2007) found music increases walking speed and induces synchronization of walking pace to the music tempo. Both of these studies imply music is able to alter gait by causing a loss of concentration during the task, with concentration diverted to listening to music. However, the results of current study suggest running is less affected by music, possibly because it is a more complex task that requires more neural control and mental concentration.

There are a few possible reasons why the tibial acceleration data did not confirm the initial hypothesis. Music has been postulated to provide performance and psychological benefits through a diversion of attentional focus or dissociation effect (Nethery, 2002; Nethery et al., 1991; Rejeski, 1985). This effect is great enough to reduce RPE, along with increasing FS, time to exhaustion, and power during endurance exercise tasks (Karageorghis & Priest, 2012a), especially in untrained participants (Brownley et al., 1995; Mohammadzadeh et al., 2008). However, based on the results of this study, the dissociation effect of music is not great enough to affect the neural pathways controlling running locomotion. Afferent signals from proprioceptors regarding fatigue and muscle function could be preferentially processed in spite of the extra musical stimuli. This could be because of the large gross muscle actions involved with running utilize large neural ensembles that are more robust to small changes in afferent stimuli (i.e from music) (Pedersen et al., 1998).

While the music was well liked by subjects, they did not personally select the music, possibly lowering the potential dissociation effect. The music may not have been loud enough for some participants, or at the correct tempo to elicit a dissociation effect, even though it was within the recommended range set out by Karageorghis and colleagues (2012). Allowing participants to choose what songs they listened to, possibly from a list of pre-approved songs, could have produced different results, although this decreases the amount of control in the study.

Another possible reason why there was no difference between music and no music conditions could be due to the exercise intensity during the trial. While subjects were asked to pick a running speed that was comfortable, many subjects appeared to be tired by the end of 30 minutes (all runners completed the 30 minute trial). Subjects exercised at ~79% intensity, based on the Karvonen HR reserve method, which is on the border between moderate and intense exercise. Music has less of an effect at higher exercise intensities when compared to low to moderate intensities (Boutcher & Trenske, 1990; Tenenbaum et al., 2004). Pennebaker & Lightner (1990) suggest that as a task becomes more complex and novel, signals involved with effort will be preferentially processed. This could mean that at higher exercise intensities an individual will deviate less from their natural running form since they are paying less attention to the music and concentrating more on running.

The lack of difference in the tibial acceleration results from the current study could also be due to using a treadmill, instead of an over-ground running task. Running gait is different during treadmill running, as the motion of running is more in reaction to the moving belt. A second major peak occurs in the accelerometer data almost immediately after the initial contact peak (see figure 4), which is not present using force platforms and over-ground running (Milner et al., 2006). Some of the actual foot strikes were not identified by the Labview batch-processing program because of these second peaks. The selection criterion for peaks was relatively high to ensure false peaks were not included in the analysis (most false peaks were excluded by not allowing any peaks 200-ms after the initial peak). Therefore, some 20-second epochs with large outliers did not have the sufficient amount of peaks necessary to be include in the analyses, and may have increased PTA and LR, due to the conservative approach used during batch-processing.

The effect of music may be more evident during a movement that is less confined than running on a treadmill. Running outdoors, where runners can self-select their running pace, may allow for more variability in gait, which is augmented by music. Individuals may also have not been familiar with running on a treadmill. This could lead to subjects paying more attention to their running form, due to anxiety about tripping and falling. Using subjects more versed in treadmill running may help remove any possible anxiety, allowing the subject to relax and dissociate from the exercise task. However, untrained subjects were chosen because of their propensity to be affected more by music than trained runners, even during treadmill running tasks (Brownley et al., 1995; Mohammadzadeh et al., 2008). This possible issue could be fixed by using a telemetered accelerometer and overground running which would allow the subject to not be confined to the treadmill or a single force platform. Another possibility would be to use an instrumented treadmill with imbedded force platforms, which would eliminate the need for the accelerometer. Testing could then be performed on two separate days, since positioning the accelerometer in exactly the same spot would not be a concern.

Overall, the PTA and LR reported in this study were unaltered by the addition of music to a treadmill running task. The dissociation effect of music may not affect the neural pathways controlling locomotion. Maintaining running biomechanics may be a more important task and is conserved even when there are other stimuli present. This lack of difference could also be due to other methodological reasons, such as the music selection, accelerometer set up, batch-processing analysis, or the one-day, continuous protocol used in this study. Considering that this appears to be the first study to quantify the effect of music on running biomechanics, additional research is still needed to confirm these results.

Physiological Response

It was hypothesized HR and FS would be augmented and RPE would be attenuated while listening to music during the exercise session. Based on the results of this study, the hypothesis concerning FS was confirmed, as there was greater FS during the music condition. Both the HR and RPE hypotheses were refuted, as HR and RPE were not different between the two music conditions. Unlike the lack of research regarding tibial accelerations, there is ample research on the physiological and psychological exercise response to music.

Five previous studies have studied FS in regards to aerobic exercise (Boutcher & Trenske, 1990; Brownley et al., 1995; Elliot et al., 2005; Edworthy & Waring, 2006; Seath & Thow, 1995). All of these studies, including the current study, used the same 11-point (-5 to +5) scale developed by Hardy and Rejeski (1989). Four of these studies reported greater FS when listening to music compared to no music (Boutcher & Trenske, 1990; Elliot et al., 2005; Edworthy & Waring, 2006; Seath & Thow, 1995). Only one reported no difference between music and no music conditions (Brownley et al., 1995). This lone outlier study did find an effect of training on FS, as untrained individuals had a greater FS when listening to fast music compared to trained runners (Brownley et al., 1995). In the studies that did find an effect of music, FS ranged from 1.5-2.4 for music and 0.29-1.80 for no music conditions (Boutcher & Trenske, 1990; Elliot et al., 2005; Edworthy & Waring, 2006). These numbers are in agreement with the current study. Therefore, the results of the current study confirm the previous findings of FS being positively affected when listening to music during aerobic exercise.

Feeling score, and therefore mood, was elevated during the music condition for multiple reasons. Listening to music during exercise may have generated positive emotional states, rather than only acting as a distractor to the exercise (Boutcher & Trenske, 1990). The music may have been associated with previous events. Multiple subjects made comments regarding past experiences with certain songs both during and after the exercise session. These associations could have been positive in nature, allowing the subject to focus attention away from the fatiguing exercise. The untrained nature of the subjects may have also played a role in the elevated feeling score, as untrained subjects derive greater psychological benefits from music. Trained individuals view music as more of a negative external distractor (Brownley et al., 1995). While subjects were instructed to truthfully report FS, they may not have wanted to upset the researchers by reporting FS values lower than zero if they were not enjoying the music.

Unlike FS, RPE did not change between the two music conditions. The literature on music and RPE is equivocal, as almost half of the reviewed studies exhibited no difference between music conditions, while the other half found decreases in RPE. No reviewed study found music increased RPE compared to no music conditions.

The interplay between music and RPE may be more complex than that of music and FS, as different types of music combined with different exercise protocols appear to affect the RPE response. Listening to classical (Potteiger et al., 2000; Szmedra et al., 1997), personally selected upbeat (Boutcher & Trenske, 1990; Nethery, 2002; Potteiger et al., 2000; Yamashita et al., 2002), fast (Potteiger et al., 2000), and relaxing music (Ghaderi et al., 2012

RamezanPour et al., 2012) all decreased RPE in studies using exercise protocols ranging from 30 minutes of submaximal (40%VO_{2max}) to cycling at 80-85% of maximum HR until exhaustion. Yet, many of these same musical choices did not affect RPE in other studies using a similar range of intensities (Brownley et al., 1995; Copeland & Franks, 1991; Edworthy & Waring, 2006; Elliot et al., 2005; Nakamura et al., 2010). In summary, music has a slightly greater affect on RPE during submaximal conditions, with faster music decreasing RPE depending on personal preference for the music, along with the length and intensity of the protocol.

The music in the current study was upbeat, fast, and popular in nature. However, this study used a continuous running protocol, with 15 minutes spent either listening or not listening to music. This is in contrast to the commonly utilized protocol, in which subjects report to the laboratory on separate days, with different music conditions on each day. The single day protocol, coupled with the moderate/high exercise intensity, are possible reasons why there was no difference in RPE between conditions. The single day protocol increased the internal validity of the study, as all measurements were made using similar conditions, but may not be as applicable to the real world since individuals rarely usually choose one music condition for the entire exercise session. Using this design, subjects may not have been allowed to fully adjust to either music condition and my still have been influenced by the other condition.

The difference between the effect of music on RPE and FS supports the notion that these two measures may be separate but related phenomena (exploratory correlation analysis revealed that RPE and FS were significantly correlated in both conditions but the conditions were not different from one another). Considering the minimal amount of time needed to collect both RPE and FS, future research should continue to evaluate both variables, as the combination may help researchers better understand the perception of the exercise.

Like RPE, there was no difference in HR between the two music conditions in the current study. This is not surprising because HR is closely related to and is one of the underlying physiological factors linked to RPE (Borg, 1982). Within the literature, the majority of studies conclude that music does not affect HR (Boutcher & Trenske, 1990; Brownley et al., 1995; Copeland & Franks, 1991; Nakamura et al., 2010; Nethery, 2002; Potteiger et al., 2000; Szabo & Leigh, 1995; Seath & Trow, 1995; Yamashita et al., 2006). This is in agreement with the results of the current study. However, three studies found that loud, fast and exciting music increased HR when performing both short submaximal (Edworthy & Waring, 2006) and maximal exercise bouts (Copeland & Franks, 1991; RamezanPour et al., 2012). On the other hand, one study (Szmedra et al., 1997) found classical music decreased HR, during a submaximal protocol (70%VO2max). Other studies using classical music did not find a reduction in HR (Potteiger et al., 2000; Szabo & Leigh, 1999). It appears that loud, fast, and upbeat music may influence HR when undergoing shorter exercise protocols (i.e. <12 minutes), but not during longer submaximal protocols.

The lack of change in HR could be due to the need to properly control and conserve HR. Heart rate, much like running biomechanics, may be controlled by too many regulatory pathways for music to be a large enough stimuli to alter the neural control of HR. During rest, music can affect HR through changes in the sympathetic nervous system (Umemura & Honda, 1998). Yet during exercise, the music stimulus may not be strong enough to alter the already present sympathetic nervous system activation from physical exertion (Yamashita et al., 2006).

The study design was not chosen to test these secondary variables (HR, RPE, FS), as it was designed to assess tibial accelerations. These secondary variables were recorded to help establish if music had a more global effect and indicate that there was not a fatigue effect, as counterbalancing negated this bias. So even though a continuous running protocol was used, the fact that FS was still different between music conditions signifies music has a strong effect on FS. This appears to be more robust than the effect of music on either HR or RPE. Future researchers should therefore utilize FS when quantifying the effects of music during any type of exercise or music intervention.

Salivary Cortisol Response

Salivary cortisol was hypothesized to be augmented when listening to music due to music's stimulatory effect. However, salivary cortisol was not different between any means, as there was no effect of time or music condition.

Two other studies have examined cortisol in response to music and exercise (Brownley et al., 1995; Ghaderi et al., 2009). Brownley et al., (1995) found an increase in plasma cortisol levels after listening to fast music compared to listening to sedative music or no music at high intensities (~160 bpm HR). However, these differences ($p<0.07$) did not reach the statistical significance established a priori ($\alpha<0.01$). Ghaderi and colleagues (2009) examined salivary cortisol in response to a submaximal exercise bout to exhaustion performed at 80-85% maximal HR. An augmented cortisol response occurred immediately post-exercise in both the motivational and no music conditions compared to the relaxation music ($p<0.01$). Listening to relaxing music produced a smaller cortisol response compared to no music at 30 minutes post-exercise ($p<0.05$). Relaxing music was not different from motivational music at 30 minutes post-exercise. Yet, it is important to note that the motivational group's running time was 41.7% longer than the relaxation group ($p<0.01$). Since the duration of exercise affects cortisol release, the differences might simply be an effect of exercise duration. The music selected for the current study was considered stimulatory or fast because of its >125 bpm tempo rate, prominent rhythmic qualities, and stimulatory lyrics adequate for repetitive tasks such as running (Karageorghis et al., 2012). Therefore, the motivational or fast music results from the previous two studies would be the best comparison. However, considering the differences between the exercise protocols, type of cortisol sampling, and the lack of standardization of when subjects came in to do their testing in this study (due to the diurnal variation of cortisol), it is difficult to compare the absolute values and results across these studies.

The effect of exercise also did not seem to be either intense enough or long enough in duration to elicit an overall change in cortisol from pre to post exercise. Previous studies found that salivary cortisol did not change after 30 minutes of submaximal exercise, but did increase at greater intensities (Van Bruggen et al., 2011). The exercise intensity used in the current study probably fell in between these two intensities as individuals exercised at 79% of their HR reserve, which equates to about 70% VO2max.

Cortisol was analyzed using a pooled mean samples analysis, instead of assaying each individual subject. This was done because cortisol was a secondary measure and to reduce the time and monetary cost of the study. This methodology has been successfully used in previous research examining exercise and salivary cortisol (Crewether, Heke, & Keogh, 2011). Studies have found differences in post-exercise serum and salivary cortisol due to a delay in serum cortisol moving to the salivary glands (O'Connor & Corrigan, 1987). However, neither the exercise intensity nor duration in this study were great enough to elicit a rise in the cortisol response that would affect the serum-salivary dynamic, ultimately affecting the salivary output. Salivary cortisol is strongly correlated to serum cortisol (Van Bruggen et al., 2011) and is easily collected during continuous endurance exercise, especially when using untrained runners. Yet, studies have found differences in post-exercise serum and salivary cortisol due to a delay in serum cortisol moving to the salivary glands (O'Connor & Corrigan, 1987). However, neither the exercise intensity nor duration in this study were great enough to elicit a rise in the cortisol response that would affect the serum-salivary dynamic, ultimately affecting the salivary output. Therefore, using salivary cortisol should be considered when wanting to approximate the biologically active proportion of cortisol in the blood and limit the technical difficulties of collecting samples during exercise.

Limitations and Future Research

The limitations and future research of the current study have been detailed throughout the discussion, and will only be summarized in this section. One limitation was allowing the subjects to choose their own speed, which caused the exercise intensity to be greater than the moderate intensity where music has the most effect. Every effort was made before the trial to inform the subjects they would be choosing their own speed, in a hope to help subjects consider what speed they could run and not choose speeds that were too easy or too hard. Future research should have the submaximal bout be done at a consistent intensity, possibly indexed to a percentage of VO2max (i.e. 60% VO2max). Another possible limitation was the single day protocol, as subjects were only able to run for 15 minutes during each condition. However, the single day protocol was also a strength of the study, as it increased the internal validity and allowed for the most accurate comparison of tibial accelerations between the two music conditions. Future research should examine using an instrumented treadmill with imbedded force platforms. This would allow for subjects to not have to wear an accelerometer or have to complete both music conditions during the same day or exercise trial. An instrumented treadmill would also allow for the measurement of stride frequency, which could help assess the entrainment effect of music. Using a telemetered accelerometer and overground running would also be a place for future research that would add to the real-world applicability of this type of research. Other limitations of the study include subjects not being able to choose their own music and the Labview batch-processing program, which may not have characterized all the foot strikes during each 20-second epoch or may have included some false peaks. Future research may also want to let subjects select music from a list of pre-approved songs within a range of music tempos (i.e. 125-140 bpm), especially if the research design is not focused on assessing the effect of small changes in music tempo on biomechanics. Further investigation of the difference between placing the tibial accelerometer on the distal or the proximal anteriomedial aspect of the tibia is also needed.

Conclusion

Listening to music does not appear to alter the biomechanics or physiological stresses of running. This is signified by a lack of change in PTA, LR, HR, RPE, or salivary cortisol, indicating no heightened risk of injury. This lack of change could be due to the methodological design or because the distracting effect of music only had a negligible influence on the cognitive processes used for locomotion and physiological stress. Yet, the distracting effect did increase feelings of wellbeing during running and was well tolerated by subjects, which is in agreement with previous studies. Therefore, listening to music should be considering a safe way to increase enjoyment and adherence to exercise programs, without negatively influencing the biomechanics of running.

APPENDICES*

Appendix A: Sample Size Calculations

A sample size calculation was carried out using appropriate sample size applications (Dupont & Plummer, 2010). Prior data that used tibial accelerations and two conditions, along with reporting clinically significant findings (Milner et al., 2006), indicate that the difference in the response of matched pairs is normally distributed with standard deviation 2.2 peak acceleration units. If the true difference in the mean response of matched pairs is 1.90 peak acceleration units, which was reported previously (Milner et al., 2006), the current will need to study at least 20 subjects to be able to reject the null hypothesis that this response difference is zero with probability (power) 0.8. The Type I error probability associated with this test of this null hypothesis is 0.05. We will recruit 10 more subjects to make sure that the appropriate power is achieved if the difference between the two groups is different in this study, which is possible due to the fact that the effect of music on tibial acceleration magnitudes during running have not been investigated.

*Materials in the Appendices are not copyrights.

Appendix B: Music Playlist

Artist	**Song**	**Song Time**	**Beats Per Minute**
Foster the People	Pumped Up Kicks	4:00	130
Capital Cities	Safe and Sound	3:13	126
Icona Pop	I Love It	2:42	126
Imagine Dragons	Radioactive	3:08	136
Calvin Harris	Sweet Nothing	3:25	128
Alex Clare	Too Close	4:18	126

Appendix C: Medical History Questionnaire

UNC
COLLEGE OF
ARTS & SCIENCES

THE UNIVERSITY
of NORTH CAROLINA
at CHAPEL HILL

DEPARTMENT OF EXERCISE AND SPORT SCIENCE
FETZER HALL
CAMPUS BOX 8700
CHAPEL HILL, NC 27599-8700
T 919.962.2021
F 919.962.0489

PRE-EXERCISE TESTING HEALTH & EXERCISE STATUS QUESTIONNAIRE

Subject ID: ____ Date______________

Email: ____________________________________ Cell Phone ____________________

Other Phone ________________ Home Address_____________________________________

Person to contact in case of emergency ____

Emergency Contact Phone ______________________ Birthday (mm/dd/yy)_____/______/______

Personal Physician ____________________________ Physician's Phone_______________

Gender_________ Age ______(yrs) Height ______(ft)______(in) Weight______(lbs)

Does the above weight indicate: a gain____ a loss____ no change____ in the past 6 months?

If a change, how many pounds?___________(lbs)

A. JOINT-MUSCLE STATUS (✓Check areas where you currently have problems)

Joint Areas
( ) Wrists
( ) Elbows
( ) Shoulders
( ) Upper Spine & Neck
( ) Lower Spine
( ) Hips
( ) Knees
( ) Ankles
( ) Feet
( ) Other______________________

Muscle Areas
( ) Arms
( ) Shoulders
( ) Chest
( ) Upper Back & Neck
( ) Abdominal Regions
( ) Lower Back
( ) Buttocks
( ) Thighs
( ) Lower Leg
( ) Feet
( ) Other__________________

B. HEALTH STATUS (✓Check if you currently have any of the following conditions)

( ) High Blood Pressure
( ) Heart Disease or Dysfunction
( ) Peripheral Circulatory Disorder
( ) Lung Disease or Dysfunction
( ) Arthritis or Gout
( ) Edema
( ) Epilepsy
( ) Multiply Sclerosis
( ) High Blood Cholesterol or Triglyceride Levels
( ) Allergic reactions to rubbing alcohol
( ) Acute Infection
( ) Diabetes or Blood Sugar Level Abnormality
( ) Anemia
( ) Hernias
( ) Thyroid Dysfunction
( ) Pancreas Dysfunction
( ) Liver Dysfunction
( ) Kidney Dysfunction
( ) Phenylketonuria (PKU)
( ) Loss of Consciousness

C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination _________________________

Physical problems noted at that time ______________________________________

Has a physician ever made any recommendations relative to limiting your level of physical exertion? _________YES __________NO

If YES, what limitations were recommended?

____

D. CURRENT MEDICATION USAGE (List the drug name and the condition being managed)

MEDICATION	CONDITION
__________________________	____________________________________
__________________________	____________________________________
__________________________	____________________________________

E. PHYSICAL PERCEPTIONS (Indicate any unusual sensations or perceptions. ✓Check if you have recently experienced any of the following during or soon after *physical activity* (PA); or during *sedentary periods* (SED))

PA	SED	
( )	( )	Chest Pain
( )	( )	Heart Palpitations
( )	( )	Unusually Rapid Breathing
( )	( )	Overheating
( )	( )	Muscle Cramping
( )	( )	Muscle Pain
( )	( )	Joint Pain

PA	SED	
( )	( )	Nausea
( )	( )	Light Headedness
( )	( )	Loss of Consciousness
( )	( )	Loss of Balance
( )	( )	Loss of Coordination
( )	( )	Extreme Weakness
( )	( )	Numbness

( ) ( ) Other________________________ ( ) ( ) Mental Confusion

F. **FAMILY HISTORY** (✓Check if any of your blood relatives . . . parents, brothers, sisters, aunts, uncles, and/or grandparents . . . have or had any of the following)

( ) Heart Disease
( ) Heart Attacks or Strokes (prior to age 50)
( ) Elevated Blood Cholesterol or Triglyceride Levels
( ) High Blood Pressure
( ) Diabetes
( ) Sudden Death (other than accidental)

G. **EXERCISE STATUS (**Please provide a precise estimation of your previous exercise habits)

Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)? YES NO

In the past *6 months*, how many minutes per week do you spend performing this type of exercise? ______ minutes

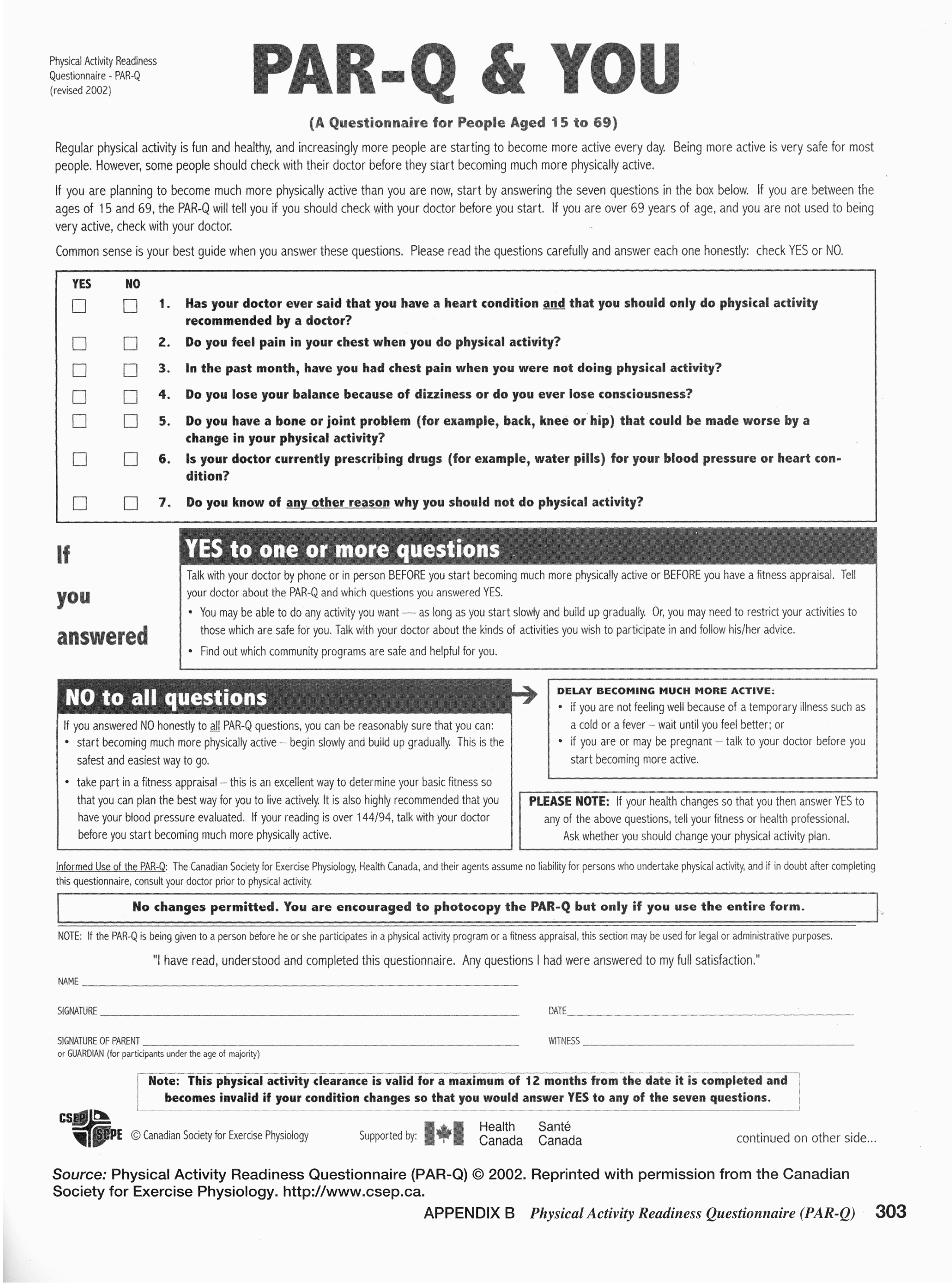
Do you regularly lift weights? YES NO

In the past *6 months*, how many minutes per week do you spend performing this type of exercise? ______ minutes

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)? YES NO

In the past *6 months*, how many minutes per week do you spend performing this type of exercise? ______ minutes

Appendix D: Physical Activity Readiness Questionnaire



Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	**1.**	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2.**	**Do you feel pain in your chest when you do physical activity?**
☐	☐	**3.**	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4.**	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5.**	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6.**	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7.**	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

Supported by: Health Canada Santé Canada

continued on other side...

Source: Physical Activity Readiness Questionnaire (PAR-Q) © 2002. Reprinted with permission from the Canadian Society for Exercise Physiology. http://www.csep.ca.

Appendix E: Data Collection Sheets

Data Collection Sheet

Subject ID: ______________________ **Date & Time:** _________________

Height: __________________ **Weight:** ______________________

Resting Heart Rate: _________________

Current training level (minutes per week): __________ **Speed (mph):** _____________

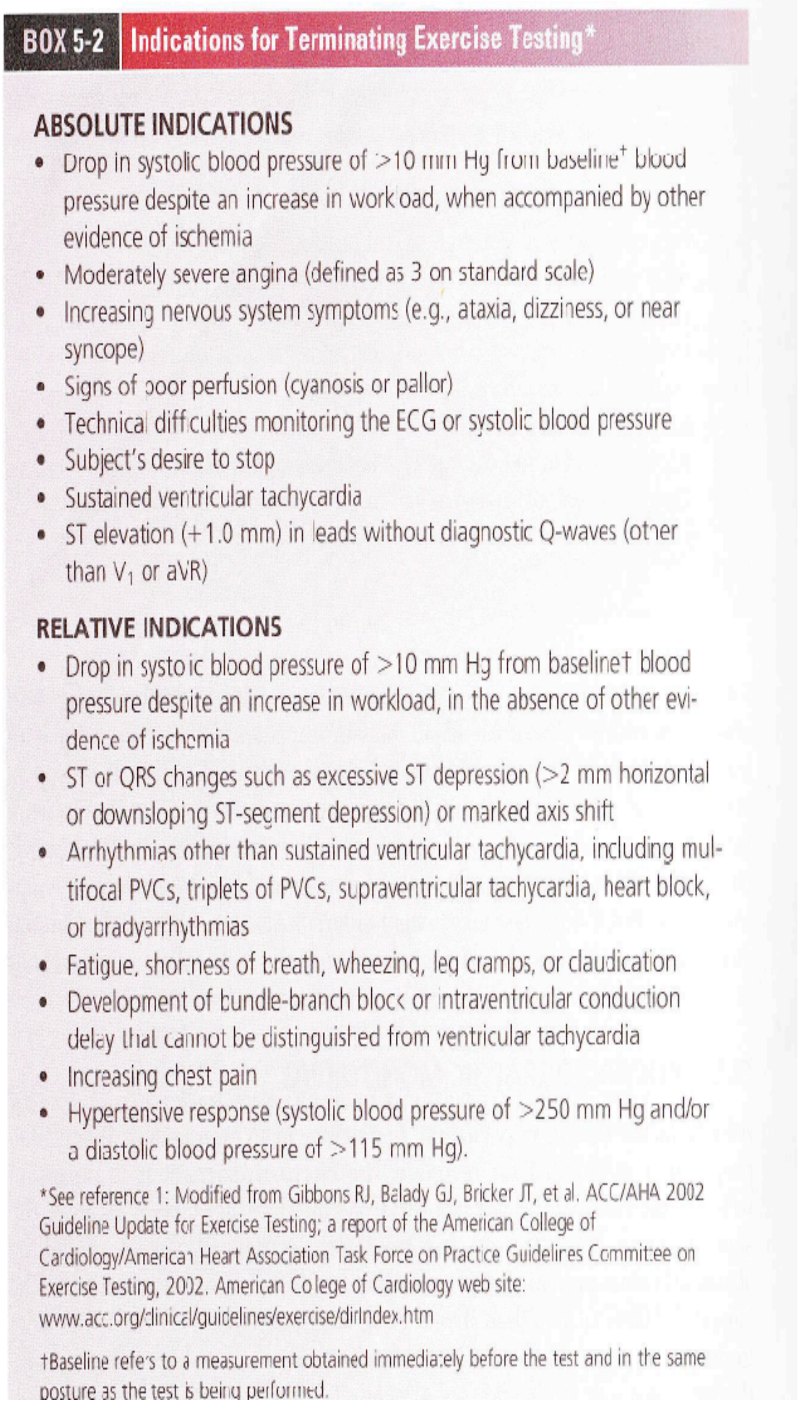
First condition (circle): M or C

Time (minutes)	Heart Rate (bpm)	RPE	FS	Acceler
3				
6				
9				
12				
15				
18				
21				
24				
27				
30				

Did you like the music?

Agree	Somewhat Agree	Neutral	Somewhat Disagree	Disagree
5	4	3	2	1

Appendix F: Indications of Terminating Exercise



BOX 5-2 Indications for Terminating Exercise Testing*

ABSOLUTE INDICATIONS

- Drop in systolic blood pressure of >10 mm Hg from baseline† blood pressure despite an increase in workload, when accompanied by other evidence of ischemia
- Moderately severe angina (defined as 3 on standard scale)
- Increasing nervous system symptoms (e.g., ataxia, dizziness, or near syncope)
- Signs of poor perfusion (cyanosis or pallor)
- Technical difficulties monitoring the ECG or systolic blood pressure
- Subject's desire to stop
- Sustained ventricular tachycardia
- ST elevation (+1.0 mm) in leads without diagnostic Q-waves (other than V_1 or aVR)

RELATIVE INDICATIONS

- Drop in systolic blood pressure of >10 mm Hg from baseline† blood pressure despite an increase in workload, in the absence of other evidence of ischemia
- ST or QRS changes such as excessive ST depression (>2 mm horizontal or downsloping ST-segment depression) or marked axis shift
- Arrhythmias other than sustained ventricular tachycardia, including multifocal PVCs, triplets of PVCs, supraventricular tachycardia, heart block, or bradyarrhythmias
- Fatigue, shortness of breath, wheezing, leg cramps, or claudication
- Development of bundle-branch block or intraventricular conduction delay that cannot be distinguished from ventricular tachycardia
- Increasing chest pain
- Hypertensive response (systolic blood pressure of >250 mm Hg and/or a diastolic blood pressure of >115 mm Hg).

*See reference 1: Modified from Gibbons RJ, Balady GJ, Bricker JT, et al. ACC/AHA 2002 Guideline Update for Exercise Testing; a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines Committee on Exercise Testing, 2002. American College of Cardiology web site: www.acc.org/clinical/guidelines/exercise/dirIndex.htm

†Baseline refers to a measurement obtained immediately before the test and in the same posture as the test is being performed.

Appendix G: Raw Cortisol Data

Salivary Cortisol	F(2,12) = .27964, p=.761		
	PRE	MID	POST
Music 1st	.362 ± .110	.274 ± .030	.329 ± .050
Music 2nd	.258 ± .110	.267 ± .030	.297 ± .050

Mean ± SD

95% Confidence Intervals			
	PRE	MID	POST
Music 1st	0.093 - 0.631	0.201 - 0.347	0.208 - 0.451
Music 2nd	-0.01 - 0.526	0.193 - 0.34	0.176 - 0.419

REFERENCES

Abraham, A., & Thomas, C. S. (1999). The effects of music tempo on self-selected exercise intensity in active female college students. *Medicine and Science in Sports and Exercise, 31*(5), S315.

Annesi, J. (2001). Effects of music, television, and a combination entertainment system on distraction, exercise adherence, and physical output in adults. *Canadian Journal of Behavioral Science, 33*(3), 193-202.

Beck, B. R. (1998). Tibial stress injuries. an aetiological review for the purposes of guiding management. *Sports Medicine (Auckland, N.Z.), 26*(4), 265-279.

Besharat, A. (2010). How co-branding versus brand extensions drive consumers' evaluations of new products: A brand equity approach. *Industrial Marketing Management; Building, Implementing, and Managing Brand Equity in Business Markets, 39*(8), 1240-1249.

Bharani, A., Sahu, A., & Mathew, V. (2004). Effect of passive distraction on treadmill exercise test performance in healthy males using music. *International Journal of Cardiology, 97*(2), 305-306.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14*(5), 377-381.

Boutcher, S. H., & Trenske, M. (1990). The effects of sensory deprivation and music on perceived exertion and affect during exercise. *Journal of Sport& Exercise Psychology, 12*, 167-176.

Brownley, K. A., McMurray, R. G., & Hackney, A. C. (1995). Effects of music on physiological and affective responses to graded treadmill exercise in trained and untrained runners. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology, 19*(3), 193-201.

Copeland, B. L., & Franks, B. D. (1991). Effects of types and intensities of background music on treadmill endurance. *The Journal of Sports Medicine and Physical Fitness, 31*(1), 100-103.

Coyle, E. F., Martin, W. H.,3rd, Bloomfield, S. A., Lowry, O. H., & Holloszy, J. O. (1985). Effects of detraining on responses to submaximal exercise. *Journal of Applied Physiology (Bethesda, Md.: 1985), 59*(3), 853-859.

Crewther, B. T., Heke, T., & Keogh, J. W. (2011). The effects of training volume and competition on the salivary cortisol concentrations of olympic weightlifters. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association, 25*(1), 10-15.

Crowell, H. P., & Davis, I. S. (2011). Gait retraining to reduce lower extremity loading in runners. *Clinical Biomechanics (Bristol, Avon), 26*(1), 78-83.

Curran, M. L. (2012). *Effects of synchronous music in sport and exercise: A meta-analytic review and field studies of ultra-distance athletes.* (Unpublished Doctoral Dissertation). University of Southern Queensland, England.

Davis, I., Milner, C., & Hamill, J. (2004). Does increased loading during running lead to tibial stress fractures? A prospective study. *Medicine and Science in Sports and Exercise, 35(Supplement)*, S58.

Edworthy, J., & Waring, H. (2006). The effects of music tempo and loudness level on treadmill exercise. *Ergonomics, 49*(15), 1597-1610.

Elliot, D., Carr, S., & Savage, D. (2004). Effects of motivational music on work output and affective responses during submaximal cycling of a standardized perceived intensity. *Journal of Sport Behavior, 27*, 134-147.

Elliott, D., Carr, S., & Orme, D. (2005). The effect of motivational music on sub-maximal exercise. *European Journal of Sport Science, 5*(2), 97-106.

Elvin, N. G., Elvin, A. A., & Arnoczky, S. P. (2007). Correlation between ground reaction force and tibial acceleration in vertical jumping. *Journal of Applied Biomechanics, 23*(3), 180-189.

Fujarczuk, K. (2006). Ground reaction forces in step aerobics. *Acta of Bioengineering and Biomechanics, 8*(2),111-118.

Ghaderi, M., Rahimi, R., & Azarbayjani, M. (2009). The effect of motivational and relaxation music on aerobic performance, rating perceived exertion and salivary cortisol in athlete meals. *South African Journal for Research in Sport, Physical Education & Recreation, 31*, 29-38.

Hardy, C. J., & Rejeski, W. J. (1989). Not what, but how one feels: The measurement of affect during exercise. *Journal of Sport & Exercise Psychology, 11*(3), 304-317.

Hauret, K. G., Shippey, D. L., & Knapik, J. J. (2001). The physical training and rehabilitation program: Duration of rehabilitation and final outcome of injuries in basic combat training. *Military Medicine, 166*(9), 820-826.

Hennig, E. M., & Lafortune, M. A. (1991). Relationships between ground reaction force and tibial bone acceleration parameters *International Journal of Sport Biomechanics, 7*, 303-309.

Hodgetts, W., Szarko, R., & Rieger, J. (2009). What is the influence of background noise and exercise on the listening levels of iPod users? *International Journal of Audiology, 48*(12), 825-832.

Holbrook, M. B., & Anand, P. (1990). Effects of tempo and situational arousal on the listener's perceptual and affective responses to music. *Psychology of Music, 18*(2), 150-162.

Karageorghis, C., Vlachopoulos, S., & Terry, P. (2000). Latent variable modelling of the relationship between flow and exercise-induced feelings: An intuitive appraisal perspective . *European Physical Education Review, 6*, 230-246.

Karageorghis, C., Jones, L., & Stuart, D. P. (2008). Psychological effects of music tempi during exercise. *International Journal of Sports Medicine, 29*(7), 613-619.

Karageorghis, C. I., Jones, L., & Low, D. C. (2006). Relationship between exercise heart rate and music tempo preference. *Research Quarterly for Exercise and Sport, 77*(2), 240-250.

Karageorghis, C. I., & Priest, D. L. (2012). Music in the exercise domain: A review and synthesis (part I). *International Review of Sport and Exercise Psychology, 5*(1), 44-66.

Karageorghis, C. I., & Priest, D. L. (2012). Music in the exercise domain: A review and synthesis (part II). *International Review of Sport and Exercise Psychology, 5*(1), 67-84.

Karageorghis, C. I., Terry, P. C., Lane, A. M., Bishop, D. T., & Priest, D. L. (2012). The BASES expert statement on use of music in exercise. *Journal of Sports Sciences, 30*(9), 953-956.

Karvonen, J., & Vuorimaa, T. (1988). Heart rate and exercise intensity during sports activities. practical application. *Sports Medicine (Auckland, N.Z.), 5*(5), 303-311.

Lac, G., Pantelidis, D., & Robert, A. (1997). Salivary cortisol response to a 30 mn submaximal test adjusted to a constant heart rate. *The Journal of Sports Medicine and Physical Fitness, 37*(1), 56-60.

Lafortune, M. A., Henning, E., & Valiant, G. A. (1995). Tibial shock measured with bone and skin mounted transducers. *Journal of Biomechanics, 28*(8), 989-993.

Matheson, G. O., Clement, D. B., McKenzie, D. C., Taunton, J. E., Lloyd-Smith, D. R., & MacIntyre, J. G. (1987). Stress fractures in athletes. A study of 320 cases. *The American Journal of Sports Medicine, 15*(1), 46-58.

Miller, T., Swank, A. M., Maire, J. T., Roberston, R. J., & Wheeler, B. (2010). Effect of music and dialog on perception of exertion, enjoyment, and metabolic responses during exercise. *International Journal of Fitness, 6*, 45-52.

Milner, C. E., Ferber, R., Pollard, C. D., Hamill, J., & Davis, I. S. (2006). Biomechanical factors associated with tibial stress fracture in female runners. *Medicine and Science in Sports and Exercise, 38*(2), 323-328.

Mizrahi, J., Voloshin, A., Russek, D., Verbitsky, O., & Isakov, E. (1997). The influence of fatigue on EMG and impact acceleration in running. *Basic Applied Myology, 2*, 111-118.

Mohammadzadeh, H., Tartibiyan, B., & Ahmadi, A. (2008). The effects of music on the perceived exertion rate and performance of trained and untrained individuals during progressive exercise. *Facta Universitatis: Series Physical Education & Sport, 6*, 67-74.

Nakamura, P. M., Pereira, G., Papini, C. B., Nakamura, F. Y., & Kokubun, E. (2010). Effects of preferred and nonpreferred music on continuous cycling exercise performance. *Perceptual and Motor Skills, 110*(1), 257-264.

Nethery, V. M. (2002). Competition between internal and external sources of information during exercise: Influence on RPE and the impact of the exercise load. *The Journal of Sports Medicine and Physical Fitness, 42*(2), 172-178.

Nethery, V. M., Harmer, P. A., & Taaffe, D. R. (1991). Sensory mediation during submaximal exercise. *Journal of Human Movement Studies, 20*, 201-211.

O'Connor, P. J., & Corrigan, D. L. (1987). Influence of short-term cycling on salivary cortisol levels. *Medicine and Science in Sports and Exercise, 19*(3), 224-228.

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2012). Prevalence of obesity in the united states, 2009-2010. *NCHS Data Brief, (82)*(82), 1-8.

Pates, J., Karageorghis, C. I., Fryer, R., & Maynard, I. (2003). Effects of asynchronous music on flow states and shooting performance among netball players. *Psychology of Sport and Exercise, 4*(4), 415-427.

Pedersen, J., Ljubisavljevic, M., Bergenheim, M., & Johansson, M. (1998). Alterations in information transmission in ensembles of primary muscle spindle afferents after muscle fatigue in heteronymous muscle. *Neuroscience, 84*(3), 953-959.

Pennebaker, J. W., & Lightner, J. M. (1980). Competition of internal and external information in an exercise setting. *Journal of Personality and Social Psychology, 39*(1), 165-174.

Potteiger, J. A., Schroeder, J. M., & Goff, K. L. (2000). Influence of music on ratings of perceived exertion during 20 minutes of moderate intensity exercise. *Perceptual and Motor Skills, 91*(3 Pt 1), 848-854.

Prassas, S., Thaut, M., McIntosh, G., & Rice, R. (1997). Effect of auditory rhythmic cuing on gait kinematic parameters of stroke patients. *Gait & Posture, 6*(3), 218-223.

Pujol, T. J., & Langenfeld, M. E. (1999). Influence of music on wingate anaerobic test performance. *Perceptual and Motor Skills, 88*(1), 292-296.

Rejeski, W. J. (1985). Perceived exertion: An active or passive process? *Journal of Sport Psychology, 7*, 371-378.

Schaffner, G., DeWitt, J., Bentley, J., Yarmanova, E., Kozlovskaya, I., & Hagan, D. (2005). Effect of load levels of subject loading device on gait, ground reaction force, and kinematics during human treadmill locomotion in a weightless environment. *National Aeronautics and Space Administration*, 1-30.

Seath, L., & Thow, M. (1995). The effect of music on the perception of effort and mood during aerobic type exercise. *Physiotherapy, 81*(10), 592-596.

Sejdic, E., Jeffery, R., Vanden Kroonenberg, A., & Chau, T. (2012). An investigation of stride interval stationarity while listening to music or viewing television. *Human Movement Science, 31*(3), 695-706.

Shung, K., de Oliveira, C. G., & Nadal, J. (2009). Influence of shock waves and muscle activity at initial contact on walk-run transition evaluated by two models. *Journal of Applied Biomechanics, 25*(2), 175-183.

Sinclair, J., Hobbs, S. J., Protheroe, L., Edmundson, C. J., & Greenhalgh, A. (2013). Determination of gait events using an externally mounted shank accelerometer. *Journal of Applied Biomechanics, 29*(1), 118-122.

Styns, F., van Noorden, L., Moelants, D., & Leman, M. (2007). Walking on music. *Human Movement Science, 26*(5), 769-785.

Szmedra, L., & Bacharach, D. W. (1998). Effect of music on perceived exertion, plasma lactate, norepinephrine and cardiovascular hemodynamics during treadmill running. *International Journal of Sports Medicine, 19*(1), 32-37.

Tenenbaum, G., Lidor, R., Lavyan, N., Morrow, K., Tonnel, S., Gershgoren, A., . . . Johnson, M. (2004). The effect of music type on running perseverance and coping with effort sensations. *Psychology of Sport and Exercise, 5*(2), 89-109.

Umemura, M., & Honda, K. (1998). Influence of music on heart rate variability and comfort--a consideration through comparison of music and noise. *Journal of Human Ergology, 27*(1-2), 30-38.

VanBruggen, M. D., Hackney, A. C., McMurray, R. G., & Ondrak, K. S. (2011). The relationship between serum and salivary cortisol levels in response to different intensities of exercise. *International Journal of Sports Physiology and Performance, 6*(3), 396-407.

Vogel, I., Verschuure, H., van der Ploeg, C. P., Brug, J., & Raat, H. (2009). Adolescents and MP3 players: Too many risks, too few precautions. *Pediatrics, 123*(6), e953-8.

Yamashita, S., Iwai, K., Akimoto, T., Sugawara, J., & Kono, I. (2006). Effects of music during exercise on RPE, heart rate and the autonomic nervous system. *The Journal of Sports Medicine and Physical Fitness, 46*(3), 425-430.