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Comparing the influence of music enjoyment and beat perception ability on spatiotemporal gait parameters among healthy young and older adults

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Abstract

Rhythmic Auditory Stimulation (RAS) involves synchronizing footsteps to music or a metronome thereby eliciting gait improvements in speed and stability among patients with Parkinson's Disease. However, gait responses are inconsistent (Dalla Bella et al., 2017). Music enjoyment may influence gait responses, but exactly how it may do this has never been empirically assessed. Moreover, individual differences in beat perception ability are likely to influence gait responses to music, particularly if instructed to synchronize to the beat. Here, we investigated whether music enjoyment influences gait, comparing responses based on beat perception ability (good vs poor) and instruction type ("walk freely" vs "synchronize to the beat"). Healthy young adults and older adults walked on a pressure sensor walkway in silence followed by music they had rated high and low in enjoyment, as well as a metronome, adjusted to 15% faster than baseline cadence. Participants were either instructed to 'freely walk' to the music or to 'synchronize to the beat'. Music enjoyment had no differential effects on gait. Young adults walked faster with longer strides to music than to the metronome, whereas older adults walked faster, taking more steps per minute to the metronome than to music. When instructed to synchronize, young adults walked faster, but older adults walked slower. Finally, young adults with poor beat perception took shorter strides to the music, regardless of the instruction type, whereas the older adults gait did not significantly differ based on beat perception ability. This study suggests that beat perception, instruction type, and age have more of an effect on gait responses than music enjoyment and should be considered to optimize RAS outcomes.

Keywords: Rhythmic Auditory Stimulation, music enjoyment, gait, beat perception, age

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List of Definitions

Gait cycle: the pattern of movements during locomotion from the initial contact with one foot to the next step with the same foot (i.e., a stride).

Spatiotemporal gait parameters: the location and timing of footsteps

Groove: the desire to move some aspect of the body to a musical stimulus

Cadence: the number of steps per unit of time (steps/min); the inverse of stride time

Stride Length: the distance between two successive footsteps of the same foot (cm)

Stride Velocity: the distance each stride covers per unit of time (cm/second)

Stride Width: the distance from the heel strike of one foot to the heel of the contralateral foot (cm)

Double Support Time: the duration two feet are on the ground at the same time (seconds)

Sensorimotor synchronization: coordination between perception and action (Repp, 2005)

Rhythmic motor entrainment: the natural ability to synchronize motor actions to an external rhythmical stimuli

Tempo: beats per minute of an auditory stimulus

Chapter 1

1 Introduction

Music has powerful properties that make us want to move, evoking enjoyment (Zatorre & Salimpoor, 2013). Listening to music has been shown to activate the motor cortex via extensive connections between the auditory and motor areas of the brain (Grahn and Rowe, 2009). As a result of these connections, we have the ability to produce coordinated movements such as tapping or head bobbing in synchrony with the music (i.e., sensorimotor synchronization; Janata, Tomic, & Haberman, 2012). Synchronizing to music, or to a metronome, has shown to be a useful strategy in neurologic music therapy facilitating improved movement patterns among patients with neurological disease affecting the motor system, such as Parkinson's disease (de Dreu, van der Wilk, Poppe, Kwakkel, & van Wegan, 2012). A therapeutic technique known as Rhythmic Auditory Stimulation (RAS) involves synchronizing footsteps to a metronome or to music and many patients with Parkinson's disease show gait improvements as a result without dopaminergic medication (McIntosh, Brown, Rice, & Thaut, 1997).

In a healthy brain, the ability to time and coordinate movements that facilitate sensorimotor synchronization involves cortical and subcortical neural structures. The basal ganglia have been suggested to be responsible for the internal timing of movements (Dalla Bella et al., 2015) as well as the perception of a beat (Grahn & Brett, 2009). In Parkinson's disease, dopaminergic neurons within the substantia nigra, a structure within the basal ganglia, degenerate, reducing the chemical signal to the motor areas of the brain responsible for internally timing and coordinating stable movements (Dalla Bella et al., 2015; Meissner et al., 2011). The resulting impairments include decreased gait speed, shortened strides, reduced arm swing amplitude, increased double support time, and a more variable gait pattern (Smulders, Dale, Carlson-Kutha, Nutt, & Horak, 2016).

Gait variability is thought to decrease gait stability and increase the risk of falling, a re-occurring health concern in older adults and patients with Parkinson's disease (Morrison, Spaulding, Holmes, & Jenkins, 2015). Although pharmacological interventions improve some aspects of gait in Parkinson's disease, certain characteristics of gait such as postural instability do not respond fully and may even worsen (Hausdorff, 2009; Spaulding, Barber, Colby, Cormack, Mike, & Jenkins, 2013). Over the past 40 years RAS has been used as a feasible non-pharmacological therapy (Lim, Van Wegen, & de Goede, 2005), which often elicits improvements in asynchronous and unstable gait (Leow, Parrott, & Grahn, 2014; Nombela, Hughes, Owen, & Grahn, 2013). In addition, many studies using RAS have reported specific improvements in spatiotemporal gait parameters**,** including increased stride velocity, stride length, and cadence (Spaulding et al., 2013). These therapeutic changes in gait parameters result in less variable strides and more postural stability (Roth & Wisser, 2004; Sejdic, Fu, Pak, Fairley, & Chung, 2012), which in turn enhances the patient's quality of life (Nieuwboer et al., 2007).

Music may have beneficial and unique properties as a RAS cue. In addition to providing a regular auditory cue, music can motivate the desire to move some aspect of the body, known as *groove* (Janata et al., 2012). Leow, Rinchon, and Grahn (2015) found that participants walked faster to music that was subjectively rated high in groove compared to music rated lower in groove. High-groove music can increase excitability of the motor system at rest (Stupacher, Hove, Novembre, Schutz-Bosbach, & Keller, 2013). In addition to groove, pleasurable reactions to music (Blood & Zatorre, 2001) may alter the individual's arousal levels and, as a result, influence gait (Naugle, Hass, Joyner, Coombes, & Janelle, 2011). For instance, an auditory stimulus can activate the sympathetic nervous system enhancing arousal levels and producing an energizing, positive affect in the individual (Salimpoor, Benovoy, Longo, Cooperstock, & Zatorre, 2009). The rewarding aspect of the stimuli can increase movement vigor (i.e., speed of movement; Mazzoni, Hristova, & Krakauer, 2007). Thus, it is possible that increasing subjective enjoyment may enhance the effects of music on gait; however, this has not yet been tested empirically. Furthermore, rehabilitation programs such as RAS have a low adherence rate (Ene, McRae, & Schenkman, 2011) and selecting the appropriate type of music can enhance the enjoyment of the rehabilitation program, increasing adherence (de Bruin, Kempster, Doucette, Doan, Hu, & Brown, 2015). Thus, music higher in enjoyment may encourage adherence to a RAS rehabilitation program and potentially lead to long-term movement improvements.

Although RAS studies with Parkinson's patients have found that music affects gait, the effect sizes, if any, are small (Dalla Bella et al., 2015). While some patients respond positively to RAS, others do not respond to the same degree or not at all (del Olmo & Cudeiro, 2005; Spaulding et al., 2013). The instructions given to the individual varies from 'synchronize footsteps to the beat' to 'freely walk'. Research to date has not compared these different instruction types in the same study, therefore it is unknown whether the instruction to synchronize to the beat is more effective than the instruction to freely walk (REF?). The beat has been defined as a regular, isochronous, 'pulse' underlying the music and producing movements in time to the music involves perceiving these reoccurring pulses (Leman, 2007). Since patients with Parkinson's disease tend to have a reduced ability to perceive a beat (Grahn and Brett, 2007) as well as poorer attentional control while walking (Yogev, Webster, & Hill, 2005), instructions to synchronize movements to the beat may require additional attention, which could worsen gait (Leow et al., 2015). Typically, the instruction to synchronize has been used in RAS studies to examine changes in gait. Therefore, the current study will be investigating if an interaction exists between beat perception ability and the instructions to synchronize to the beat by examining the response in gait of good and poor beat perceivers in either the ‘free walking’ or ‘synchronized’ instruction type. This between subject design will allow us to determine whether the instruction to synchronize to the beat hinders gait among poor beat perceivers as well as further examine which instruction type elicits the most optimal gait performance, regardless of specific beat perception abilities. Together, the knowledge gained regarding the influence of enjoyment, beat perception ability, and instruction type could enhance the functional outcomes of patients undergoing music RAS.

Another aspect of RAS that varies in the literature is the tempo of music played, ranging from 10% slower than preferred cadence to 22.5% faster than preferred cadence. The tempo is a property of music that has the ability to influence gait as the beat frequency elicits activity in the premotor cortex (Kornysheva et al., 2010). Some studies involving patients with Parkinson’s disease compared gait responses when synchronizing to music 10% slower than preferred cadence and 10% faster than preferred cadence (Williams et al., 2006), while others matched the music to the individual’s preferred cadence (Moens et al., 2017). These previous studies have mixed findings, with increased stride velocity and cadence, but not stride length, when synchronizing to music 10% faster than preferred cadence compared to the decreased gait velocity and cadence, but increased stride length, when synchronizing to music 10% slower than preferred cadence (Williams et al., 2006). When the music was matched to preferred cadence, stride length improved, but gait velocity did not significantly change from baseline (Moens et al., 2017). Rochester, Burn, Woods, Godwin, and Nieuboer (2009) matched the metronome to preferred cadence and found that, compared to baseline, cadence increased significantly but stride velocity and stride length did not when instructed to synchronize (Rochester, Burn, Woods, Godwin, & Nieuwboer, 2009). Since patients have shorter strides and slower gait velocities than healthy older adults, increasing stride length and gait velocity are both important, positive, outcomes of auditory cueing which leads to improved locomotion, quality of life, and independence (Spaulding et al., 2013).

As movement speed has been shown to increase in the context of a rewarding stimulus, we hypothesized that enjoyable music would lead to faster stride velocity, longer stride length, higher cadence, and less stride-to-stride variability compared to unenjoyable music. Furthermore, based on the idea that beat perception ability influences the difficulty of synchronization (Leow et al., 2014), we predicted that instructions to synchronize would improve gait parameters less among poor beat perceivers than good beat perceivers, and that instruction to walk freely would elicit greater gait improvements in poor beat perceivers than instructions to synchronize. All music was adjusted to 15% faster than the participant's initial baseline cadence (i.e., preferred cadence) because previous research found that this adjustment elicited increases in gait speed and reductions in gait variability (Leow et al., 2015).

Chapter 2

2 Methods

2.1 Participants

Eighty- two healthy younger adults were recruited via Western University's undergraduate participant pool and 98 healthy older adults, 50 years or older, were recruited via poster advertisements as well as verbal announcements at the Western Senior Alumni Program to participate in this study (young adults: $M = 22$ years, $SD = 2.88$; older adults: $M = 66$ years, $SD = 9.14$). Testing was conducted in a gait laboratory, and participants were compensated 5$/half an hour. We excluded those who were unable to walk unaided, walked on the mat improperly, or who were two standard deviation or more below the mean proportion change score for a certain gait parameter. One participant from the young adult group was excluded because their change in stride velocity during music and metronome conditions relative to baseline was two standard deviations below the mean of rest of the sample, and one participant was excluded from the older adult group because their change in cadence during music and metronome conditions relative to baseline was two standard deviations below the rest of the sample. In addition, three participants were excluded from the older adult group because of improper walking on the mat preventing accurate processing of steps. The University of Western Ontario Human Research Ethics Board approved the study (see Appendix A).

2.2 Materials

2.2.1 Demographic and Music Training Questionnaire. A two-part questionnaire was created where participants answered questions regarding their musical preference, musical experience (i.e., dance classes or music classes), neurological state, age, gender, and drug use. The first part of the questionnaire collected demographic information and the second part collected years of musical training, since music training may co-vary with beat perception ability.

2.2.2 Stimuli. The music clips were various genres including: Electronic Dance Music, Country, Pop, Hip-Hop/Rap, and Jazz (see Table 1 and Table 2). In order to have enough songs to determine songs higher in enjoyment and lower in enjoyment, 32 music clips were chosen based off of pilot ratings; selecting those low in familiarity but high in groove. Participants walked to 16 full-length versions of the music clips that they had rated for eight walks. In addition, they walked to metronome tracks for the same length of time. The steady isochronous tone repeated 15% faster than the participant's initial baseline cadence was included to observe the differential influence a metronome has on gait compared to music (Styns et al., 2007). Using Audacity (http://audacity.sourceforge.net), each full-length music clip was adjusted so that the tempo was 15% faster than baseline cadence, leaving pitch unaltered. All clips were normalized to the same relative volume.

2.2.3 Music Ratings. Participants rated 32 10-second instrumental music excerpts prior to the gait portion of the experiment. After each excerpt, participants rated it for familiarity, groove, enjoyment, and beat salience: Familiarity: How familiar are you with this piece of music? 1 = never heard it before, 100 = I have heard this song multiple times before and can predict what happens next; Groove: How much does this piece of music make you want to move to it? 1 = no desire to move, 100 = strong desire to move; Enjoyment: How much do you enjoy this piece of music? 1 = strongly dislike, 100 = strongly like; and Beat salience: How strong is the beat in this piece of music? 1 = very weak, 100 = very strong. Each clip of music was adjusted such that the beat was at a rate 15% faster than the participant's preferred walking cadence (determined as described below) for each participant. This ensured that ratings were of the music that was later walked to by that participant in the gait portion of the experiment, as that music was also 15% faster than baseline cadence. The songs the participant walked to were selected based on their own ratings. A MATLAB script was used to attempt to maximize the difference in enjoyment for the high and low enjoyment categories, but also to minimize differences in groove, and select songs that were less familiar and high in beat salience. The script first selected songs in which familiarity was rated as 50 or less, and beat salience was 50 or higher. Then, the script ran an iterative series of t-tests on enjoyment and groove to choose two groups (high enjoyment and low enjoyment) of eight songs that statistically differed in ratings of enjoyment, but were not statistically different in ratings of groove. Thus, the algorithm attempted to maximize the difference in enjoyment while minimizing differences in other ratings.

2.2.4 The Beat Alignment Test (BAT). The BAT consists of production and perception subtests (Iverson & Patel, 2008)[33]. Each test was run using E-Prime on a laptop computer. The perception subtest involved listening to 17 music clips with a superimposed beep that was either on the beat of the music or off the beat. Participants pressed the 'Y' key if the beep was perceived to be *on* the beat of the music, and the 'N' key if it was not. Participants then rated how certain they felt about their answer: 3 = very certain, 2 = somewhat certain, and 1 = guessing. In the production subtest, participants tapped the spacebar along to the beat of the music in 12 different musical excerpts. Each music clip was followed by a familiarity rating: 1 = never heard it, 2 = somewhat familiar, 3 = very familiarity.

2.3 Procedure

After providing informed consent, the participant completed the perception subtest of the BAT. Then a baseline gait measurement was taken. For all gait trials, the participant began by standing at a taped line 1.78m away from the edge of the 16 foot pressure sensor walkway (Zeno, Protokinetics, Inc), then walked across the walkway to a taped line marked 1.78m off the opposite end of the mat. They turned and continued walking until they had walked the length of the mat eight times. Walking to a line off the mat captures the steady-state walking, minimizing the contribution of acceleration and deceleration phases (Hollman et al., 2010). Next, the participant completed the production subtest of the BAT while the researcher processed the initial baseline gait measurement to obtain the participant’s cadence. Upon completion of the BAT, the participant rated the 32 musical excerpts at a tempo 15% faster than their preferred cadence. Finally, participants completed the gait portion of the experiment. The participant was either instructed to ‘walk freely to the music’ or to ‘synchronize to the beat’ to compare the influence of instruction type between subjects. First, participants completed two practice walking trials, with the music played through speakers so the researcher could ensure participants who were instructed to synchronize understood the task and gave them the opportunity to ask questions if needed. Next, the participant put on wireless headphones for the remaining walking trials in order to prevent experimenter biases. Volume was set at the same initial level, but the participant could ask to have it adjusted up or down for comfort. On each cued trial, the music or metronome played until the participant had completed eight lengths of the sensor walkway. After the first eight cued trials, as well as at the end of all 18 cued trials, the participants walked without music to assess any changes in gait across the experiment (see Figure 1). To prevent fatigue, the music and the metronome were randomly played, the participant was offered water, and breaks could be taken at any time. Finally, the participants completed a demographic questionnaire and then were debriefed.

Chapter 3

3 Data Analysis: Scoring the data

3.1 Beat perception ability: BAT perception test

The percentage of excerpts correctly identified as ‘on’ or ‘off’ the beat was used to measure beat perception ability. Thus, the average was taken of the correct answers in Microsoft excel indicating the percentage correct. This resulted in a score between 0 and 1 (0 if all incorrect, 1 if all correct). Next, the median perception score was found to classify participants as a poor beat perceiver or a good beat perceiver. For example, the good beat perceivers had a score at or above the median score whereas the poor beat perceivers were below the median.

3.2 Tapping performance: BAT production test

Accuracy and variability of synchronization to the musical beat was assessed using the BAT. The timing of each tap was compared to the nearest beat time in the music. To measure accuracy of synchronization, mean asynchrony (the average absolute difference between each tap time and the nearest beat time) was calculated. The coefficient of deviation (CDEV) was used as another indication of one’s synchronization accuracy, however it compared how close the individual’s intertap interval was to the nearest interbeat interval of the stimulus rather than whether the taps were in the same phase with the beat. First, an absolute difference between the interbeat interval and the intertap interval for each song trial was calculated. Next, these differences were divided by the individual’s average intertap interval for each trial to produce the trial-by-trial CDEV. Then, a single value for each participant was calculated by calculating the mean across all trials. This determined, on average, whether the taps were accurately timed to the beat for each song trial. The coefficient of variability (CoV) was used to measure tapping variability, as opposed to synchronization accuracy, and was calculated by dividing the standard deviation of the intertap interval by the average intertap interval.

Each participant's raw tapping data was run through a MATLAB script to obtain the CoV, CDEV, and the average asynchrony scores.

3.3 Spatiotemporal gait parameters

Each walking trial was recorded and processed in a computer software program called ProtoKinetics Movement Analysis Software (PKMAS). Gait parameters such as stride velocity (the distance of a stride per unit of time; cm/second), stride length (the distance between two steps of the same foot; cm), cadence (steps per minute), stride width (the distance between two contralateral footsteps; cm), double support time (duration two feet are in contact with the ground; seconds), and gait variability were measured. Stride velocity can be increased by either longer stride length or shorter stride time or both, as stride velocity is simply the ratio of stride length and stride time. The stride-to-stride fluctuations indicating the degree of gait stability and control (i.e., gait variability) was analyzed by calculating the coefficient of variability (CV), the standard deviation (SD) divided by the mean (Schaefer, Lovden, Wieckhorst, & Lindenberger, 2010). Double support time and stride width were also analyzed as a measure of gait stability as increases indicate a reduction in balance control or cautious walking, common among healthy older adults as well as patients with a basal ganglia disorder (Bryant et al., 2011). Each gait parameter within each cued condition was subtracted from the initial baseline measurement to determine how much the gait parameter changed from walking in silence to walking with music or a metronome. These change scores were then normalized to the initial baseline gait parameter, to express all participant's changes in gait as proportion changed and prevent individual body or kinematic differences, such as leg length or height, from influencing the measurements. The following equation was used to determine the proportion change score from baseline:

$$\text{Proportion change score} = \frac{\text{Gait parameter} - \text{Initial baseline gait parameter}}{\text{Initial baseline gait parameter}}$$

Lastly, the proportion change scores across the eight high enjoyment and eight low enjoyment music clips were averaged. Since the metronome has a simple rhythmic pattern to adjust movements to, two metronome tracks were averaged (ref). Additionally, the proportion change score is not determining whether the group of individuals significantly changed from the initial baseline gait but rather determining whether the average gait change among individuals, of a certain beat perception ability, was significantly different compared to the stimuli and instruction manipulations.

Chapter 4

4 Results

4.1 Beat Alignment Test Perception Scores

***4.1.1 Young Adults*.** BAT perception scores ranged from 0.29 to 1 (*M* = 0.67, *SD* = 0.16)[3]. The median score was 0.68, therefore those who scored below 0.68 were placed in the poor beat perception ability (n = 40) whereas those who scored above 0.68 were placed in the good beat perception ability (n = 41). An independent samples t-test showed, on average, that the poor beat perceivers had significantly fewer years of music training than the good beat perceivers (*M* = 3.13, *SD* = 3.98; *M* = 9.02, *SD* = 6.31, respectively; t(80) = -5.06, $p < 0.001$).

4.1.2 Older Adults. BAT perception scores ranged from 0.17 to 1 (*M* = 0.64, *SD* = 0.16). The median score was 0.64, therefore those who scored below 0.64 were placed in the poor beat perceiver group (n = 40) whereas those who scored above 0.64 were placed in the good beat perceiver group (n = 40). There were 14 older adults who scored exactly 0.64 and thus were placed in the good beat perceiver group due to the reduced number of participants who scored above 0.64 (thus a total n = 54 for the good beat perceiver group). Unlike the young adults, the poor beat perceivers did not significantly differ in years of formal music training compared to the good beat perceivers (*M* = 5.27, *SD* = 10.09; *M* = 5.35, *SD* = 6.24, respectively; t(96) = -.05, $p = .96$).

The beat perception score range, mean, and standard deviation for both younger and older adults were similar to past research (Leow et al., 2015).

4.2 Average Ratings

Each music clip was rated on familiarity, groove, enjoyment, and beat salience. The ratings were used to select high and low enjoyment songs for each individual. For each individual, the average of the ratings was calculated for the eight selected highly enjoyed songs and the eight selected less enjoyed songs. Then, the average ratings for enjoyment, familiarity, groove, and beat salience were compared between selected high and low enjoyment songs. We aimed to maximize the difference in enjoyment between high and low enjoyment songs, but to minimize differences in familiarity, groove, and beat salience. However, paired two sample t-tests revealed that all the ratings on average significantly differed between the high and low enjoyment songs in both young and older adults: Familiarity [$t(149) = 10.98$, $p < .001$], Groove [$t(149) = 19.97$, $p < .001$], Enjoyment [$t(149) = 27.68$, $p < .001$], Beat Salience [$t(149) = 10.79$, $p < .001$]; (see Appendix B). Although the ratings differed between the high and low enjoyment songs, the average familiarity rating (*M* = 15) was on the low end of the familiarity scale, and the average beat salience (*M* = 61) was on the higher end of the beat salience scale. Provided that the difference between the songs rated high in enjoyment (*M* = 59; *SD* = 21.59) and the songs rated low in enjoyment (*M* = 14; *SD* = 15.42) was larger than the differences among the other ratings (i.e., 45 points on a 100-point scale): Familiarity (*M* = 20, *SD* = 18; *M* = 10, *SD* = 13), Groove (*M* = 50, *SD* = 21; *M* = 21, *SD* = 16), and Beat Salience (*M* = 70, *SD* = 22; *M* = 53, *SD* = 23).

4.3 Correlations between Beat Perception, Beat Production and Music Training

To determine the correlations between beat perception, beat production, and music training, each of the variables were first mean centered where each individual score was subtracted from the average value. This was done so that the variables could be compared on a similar, continuous, scale. Next, the mean centered values were entered into a Pearson bivariate correlation. The following correlations were important to note as music training, beat perception ability and beat production co-vary, thus assisting in interpreting what drives the effects on gait.

4.3.1 Beat Perception vs Coefficient of Tapping Variation.

Young adults. There was a significant, moderate negative correlation (r = -.512, p < .001; see Figure 2) between BAT perception scores and tapping variability, indicating that individuals with better performance on the beat perception task had lower tapping variability (i.e., more stability in tapping the beat) compared to those with a lower percentage of correct responses.

Older adults. There was a significant, weak negative correlation (r = -.25, p = .01; see Figure 2) between BAT perception scores and tapping variability, indicating that individuals with better performance on the beat perception task had lower tapping variability.

4.3.2 Beat Perception vs Coefficient of Deviation.

Young adults. There was no significant correlation between BAT perception scores and CDEV, (r = -.06, p = .59; see Figure 2), indicating that beat perception and accuracy in producing the correct beat rate were unrelated.

Older adults. There was no significant correlation between BAT perception scores and CDEV (r = -.05, p = .61; see Figure 2), indicating that beat perception and accuracy in producing the correct beat rate were unrelated.

4.3.3 Beat Perception vs Average Asynchrony.

Young adults. There was a significant, weak negative correlation (r = -.24, p = .03; see Figure 2) between BAT perception score and tapping asynchrony, indicating that those with better beat perception also aligned their taps to the beat more accurately.

Older adults. There was no significant negative correlation (r = -.08, p = .39; see Figure 2) between BAT perception score and tapping asynchrony, indicating that those with better beat perception did not also align their taps to the beat more accurately.

4.3.4 Beat Perception vs Music Training.

Young adults. There was a significant, moderate positive correlation (r = .528, p < .001; see Figure 3) between BAT perception score and years of musical training.

Older Adults. There was no significant correlation between BAT perception score and musical training in older adults (r = .10, p = .336; see Figure 3).

4.3.5 Coefficient of Tapping Variation vs Musical Training.

Young adults. There was a significant, moderate negative correlation (r = -.34, p = .002; see Figure 3) between musical training and tapping variability, indicating that individuals with more years of music training had lower tapping variability.

Older adults. There was no significant correlation (r = - .175, p = .09; see Figure 3) between musical training and tapping variability.

4.4 Comparing the Younger and Older Adults in the same analysis

4.4.1 Analysis of variance (ANOVA). A 3 x 2 x 2 x 2 repeated measures mixed ANOVA was carried out using the Statistical Package for Social Science (SPSS) including younger and older adults in the same analysis: 3 [*stimulus:* metronome vs high enjoyment vs low enjoyment] x 2 [*beat perception ability:* good vs poor beat perceiver] x 2 [*instruction type:* free walking vs synchronized instruction] x 2 [*age group*: younger vs older adults] on each gait parameter of interest. This analysis had beat perception ability, age group, and instruction type all entered as between subjects. The combined ANOVA indicated significant main effects of age, beat perception ability and instruction type as well as interactions between the stimuli and age; stimuli, instruction and age; and instruction and age for gait speed. Since the years of formal musical training and BAT perception test score often co-vary, a repeated measures mixed analysis of covariance (ANCOVA) was carried out in SPSS with music training and BAT perception test score entered as a covariate. In the ANCOVA, there were interactions with musical training, thus musical training was kept in as a covariate.

4.4.2 Age differences to the stimuli. There was a significant interaction between age and stimuli for cadence [$F(1.64, 264.65) = 10.61$, $p < .001$, $n^2_p = .06$], stride length [$F(1.34, 215.3) = 7.46$, $p = .003$, $n^2_p = .04$], stride velocity [$F(1.69, 271.7) = 23.43$, $p < .001$, $n^2_p = .13$], and double support time [$F(1.73, 278.41) = 10.07$, $p < .001$, $n^2_p = .06$]. This indicated that younger adults had more steps per minute, as well as longer, faster and briefer strides to both high and low enjoyment music compared to the metronome whereas the older adults had more steps per minute, as well as longer, faster and briefer strides to the metronome compared to both high and low enjoyment music (see Table 3). In regards to gait variability, there was a significant interaction between age and stimuli for stride length [$F(1.55, 247.18) = 4.29$, $p = .02$, $n^2_p = .03$] and stride velocity [$F(1.28, 202.93) = 5.43$, $p = .01$, $n^2_p = .03$]. Thus, the younger adults showed no differences in stride length and stride velocity variability whereas the older adults showed increased stride length and stride velocity variability to both high and low enjoyment music compared to the metronome (see Table 4).

4.4.3 Age differences with instruction type. There was a significant interaction between age and instruction for stride length [$F(1, 161) = 4.39$, $p = .04$, $n^2_p = .03$] and stride velocity [$F(1, 161) = 9.55$, $p = .002$, $n^2_p = .06$]. Thus, young adults took longer and faster strides when instructed to synchronize to the beat compared to when instructed to freely walk whereas older adults took longer and faster strides when instructed to freely walk compared to when instructed to synchronize to the beat (see Table 3). In regards to gait variability, there was a significant interaction between age and instruction for stride length [$F(1, 159) = 10.10$, $p = .002$, $n^2_p = .06$], stride velocity [$F(1, 159) = 5.07$, $p = .03$, $n^2_p = .03$], and double support time [$F(1, 159) = 5.08$, p

= .03, n^2_p = .03] variability. Thus, the young adults showed no difference in variability between instruction types for stride length and double support time variability whereas the older adults showed increased variability with the instruction to synchronize to the beat compared to the instruction to freely walk for stride length and double support time variability. Furthermore, the younger adults showed decreased stride velocity variability when instructed to freely walk compared to when instructed to synchronize to the beat whereas the older adults showed increased stride velocity variability when instructed to synchronize to the beat compared to when instructed to freely walk (see Table 4).

4.4.4 Main effect of instruction type. There was a main effect of instruction type for stride length [$F(1, 161) = 20.2$, $p < .001$, n^2_p = .11]. Therefore, regardless of age, the instruction to synchronize to the beat shortened strides compared to the instruction to freely walk (see Table 3). In regards to gait variability, there was a main effect of instruction type for stride time [$F(1, 159) = 27.75$, $p < .001$, n^2_p = .15], stride length [$F(1, 159) = 9.46$, $p = .002$, n^2_p = .06], stride velocity [$F(1, 159) = 19.15$, $p < .001$, n^2_p = .11], and double support time [$F(1, 159) = 7.6$, $p = .007$, n^2_p = .05] variability. Thus, regardless of the age group, the instruction to synchronize to the beat elicited increased variability compared to the instruction to freely walk (see Table 4).

4.4.5 Main effect of age. There was a significant main effect of age for stride length [$F(1, 161) = 8.87$, $p =.003$, n^2_p = .05] and stride velocity [$F(1, 161) = 15.99$, $p < .001$, n^2_p = .09]. Thus, regardless of instruction type or beat perception ability, younger adults had longer and faster strides than the older adults (see Table 3). In regards to gait variability, there was a main effect of age for stride time [$F(1, 159) = 4.28$, $p =.04$, n^2_p = .03], stride length [$F(1, 159) = 18.13$, $p < .001$, n^2_p = .10], and stride velocity variability [F(1, 159) = 23.10, $p < .001$, n^2_p = .13]. Thus, regardless of instruction type or beat perception ability, younger adults had less gait variability compared to the older adults (see Table 4).

4.4.6 Main effect of beat perception ability. There was a significant main effect of beat perception ability for stride length [$F(1, 161) = 4.62$, $p = .03$, $n^2_p = .03$] and stride velocity [$F(1, 161) = 5.14$, $p = .02$, $n^2_p = .03$]. Therefore, regardless of age, poor beat perceivers had shorter and slower strides compared to the good beat perceivers (see Table 3). In regards to gait variability, there was no significant difference between poor and good beat perceivers (see Table 4).

4.4.7 Main effect of stimuli. There was no significant difference between high and low enjoyment music, however there was a main effect of stimuli for cadence [$F(1.64, 264.65) = 13.74$, $p < .001$, $n^2_p = .08$], and stride velocity [$F(1.69, 271.7) = 8.11$, $p = .001$, $n^2_p = .05$]. Therefore, regardless of age, the metronome elicited more steps per minute and faster strides compared to both the high and low enjoyment music (see Table 3). In regards to gait variability, there was no significant difference between high and low enjoyment music, however there was a significant main effect of the stimuli with increased stride time [$F(1.48, 236.12) = 4.79$, $p = .02$, $n^2_p = .03$], stride length [$F(1.55, 247.18) = 7.25$, $p = .002$, $n^2_p = .04$], stride velocity [$F(1.28, 202.93) = 4.15$, $p = .03$, $n^2_p = .02$], and double support time [$F(1.78, 283.69) = 6.04$, $p = .004$, $n^2_p = .04$] variability to both high and low enjoyment music compared to the metronome (see Table 4).

4.5 Determining the Influences on Gait in separate analyses

Since there were significant differences between the younger and older adults in the combined ANCOVA, we also analyzed the younger and older adults in separate ANCOVA’s to determine the influences on gait when age is a within groups variable. A 3 [*stimulus:* metronome vs high enjoyment vs low enjoyment] x 2 [*beat perception ability:* good vs poor beat perceiver] x 2 [*instruction type:* free walking vs synchronized instruction] repeated measures mixed ANCOVA was carried out, with beat perception ability and music training mean centered and entered as covariates. For the older adults, there were no main effects nor interactions with music training, so music training was removed from the ANCOVA and only the BAT perception test score was included. For the younger adults, effects of both music training and BAT perception test score were observed, so both covariates were retained. As CoV and BAT perception test score were correlated, only BAT perception test score was included as a covariate. However, when the COV was used instead of BAT perception score, the results were similar. The results of the young adult ANCOVA for cadence, stride velocity, and stride length can be found in Figure 4 whereas Figure 5 includes the results for stride width and double support time. The results of the older adult ANCOVA for cadence, stride velocity, and stride length can be found in Figure 6 whereas Figure 7 includes the results for stride width and double support time.

4.5.1 Main effect of stimuli

Young adults. Contrary to our hypothesis, there was no difference between high enjoyment and low enjoyment music on gait. In young adults, there was a main effect of the stimulus on stride velocity and stride length where RAS elicited faster strides to both high enjoyment and low enjoyment music than to the metronome track [$F(1.64, 121.11) = 3.48$, $p = .04$, $n^2_p = .045$] and longer strides to the music compared to the metronome [$F(1.67, 123.56) = 5.80$, $p = 0.006$, $\eta^2_p = .073$]. Cadence (steps per minute) increased to both music and the metronome relative to baseline, but similarly [$F(2, 148) = .048$, $p = .94$, $n^2_p = .001$]; see Figure 4. In regards to gait stability, there was no significant main effect of the stimulus on stride width and double support time [$F(1.43, 106.14) = .76$, $p = .43$, $n^2_p = .01$; $F(2, 148) = 2.04$, $p = .13$, $n^2_p =$

.03, respectively]; see Figure 5. In addition, young adults did not significantly change in gait variability between the music and the metronome: stride time variability [F(2, 148) = 1.82, p = .17, n^2_p = .02], stride length variability [F(1.27, 94.23) = .34, p = .62, n^2_p = .005], stride velocity variability [F(1.67, 123.90) = .70, p = .48, n^2_p = .009], stride width variability [F(2, 148) = 2.73, p = .07, n^2_p = .04], and double support time variability [F(1.67, 123.26) = .89, p = .40, n^2_p = .01]; see Figure 4 and Figure 5.

Older adults. Contrary to our hypothesis, there was no difference between high enjoyment and low enjoyment music on gait. Among older adults, there was a main effect of the stimulus on stride velocity and cadence where RAS elicited slower strides and less steps per minute to both high enjoyment and low enjoyment music compared to the metronome track [F(1.70, 153.02) = 25.80, p < .001, n^2_p = .22; F(1.63, 146.78) = 21.32, p < .001, n^2_p = .19]. In contrast to the young adults, there was no main effect of the stimulus on stride length [F(1.22, 110.11) = 1.84, p = .18, n^2_p = .020]; see Figure 6. In regards to gait stability, there was no significant main effect of the stimulus on stride width [F(2, 180) = 1.64, p - .20, n^2_p = .02], however the duration of double support time was briefer to the metronome than the music [F(1.64, 147.55) = 9.98, p < .001, n^2_p = .10]; see Figure 7. The change in double support time should be interpreted with caution as double support time normally reduces when stride velocity increases (Beauchet, Dubost, Hermann, & Kressig, 2005). In addition, in contrast to the young adults, older adults increased in gait variability when walking to music compared to the metronome, except for stride width variability: stride time variability [F(1.33, 110.69) = 5.24, p = .02, n^2_p = .06], stride length variability [F(1.64, 148.05) = 11.64, p < .001, n^2_p = .12], stride velocity variability [F(1.25, 112.64) = 7.39, p = .004, n^2_p = .08], stride width variability [F(1.51, 135.90) = .30, p = .68, n^2_p = .003], and double support time variability [F(1.76, 158.38) = 9.63, p < .001, n^2_p = .10]; see Figure 6 and Figure 7.

4.5.2 Influence of the instruction to synchronize

Young adults. In young adults, synchronizing compared to free walking resulted in a higher cadence [F(1, 74) = 6.21, p = .015, n^2_p = .077] and faster stride velocity [F(1, 74) = 11.78, p = .001, n^2_p = .14], but did not significantly influence stride length [F(1, 74) = .04, p = .84, n^2_p = .001]; see Figure 4. However, these increases in gait speed did not reach 15% as the greatest proportion change score for cadence was .12 (12% faster). In regards to gait stability, instructions to synchronize resulted in briefer double support time [F(1, 74) = 5.14, p = .03, n^2_p = .06], but did not significantly influence stride width [F(1, 74) = 1.06, p = .31, n^2_p = .01]; see Figure 5. In addition, there was a significant increase in stride time variability and a decrease in stride velocity variability with the instruction to freely walk [F(1, 74) = 13.79, p < .001, n^2_p = .16; F(1, 74) = 11.43, p = .001, n^2_p = .13, respectfully], but no significant change in stride length variability [F(1, 74) = 1.09, p = .30, n^2_p = .003]; see Figure 4. There was also no significant change in double support time variability [F(1, 74) = .64, p = .42, n^2_p = .009]; see Figure 5.

Furthermore, there was a significant interaction between the stimulus and instruction type for double support time: double support time was shorter to the music than the metronome in the free walking condition, but shorter to the metronome than music in the synchronized condition [F(2, 148) = 5.68, p = .004, n^2_p = .07]; see Figure 5.

*Older adults***.** In contrast to young adults, synchronizing compared to free walking resulted in shorter stride length [F(1, 90) = 24.77, p < .001, n^2_p = .22] and slower stride velocity [F(1, 90) = 8.60, p = .004, n^2_p = .09], and did not significantly influence cadence [F(1, 90) = .08, p = .77, n^2_p = .001]; see Figure 6. In regards to gait stability, the instruction to synchronize did not significantly influence stride width [F(1, 90) = .63, p = .43, n^2_p = .007] or double support time [F(1, 90) = .1.56, p = .21, n^2_p = .02]; see Figure 7. In addition, there was a significant increase in stride time variability [F(1, 90] = 16.47, p < .001, n^2_p = .15], stride length variability [F(1, 90) = 18.18, p < .001, n^2_p = .17], stride velocity variability [F(1, 90) = 18.76, p < .001, n^2_p = .17], and double support time variability [F(1, 90) = 14.65, p < .001, n^2_p = .14] with the instruction to synchronize; see Figure 6 and Figure 7.

Furthermore, there were significant interactions between the stimulus and instruction type, in which the synchronized condition had a higher cadence to the metronome than both high and low enjoyment music [F(1.63, 146.77) = 8.20, p < .001, n^2_p = .08] and a slower stride velocity to both high and low enjoyment music than metronome [F(1.70, 1.53.02) = 6.72, p = .003, n^2_p = .07]; but no significant interaction between stimulus and instruction type for stride length [F(1.22, 110.11) = .05, p = .87, n^2_p = .001], see Figure 6. In regards to gait stability, there was no significant interactions between the stimulus and instruction type: stride width [F(2, 180) = 1.97, p = .14, n^2_p = .02] and double support time [F(1.64, 147.55) = 1.18, p = .30, n^2_p = .01]. The synchronized condition elicited increased double support time variability to both high and low enjoyment music compared to the metronome, whereas in the free walking condition, double support time variability across the stimuli did not differ [F(1.76, 158.38) = 4.91, p = .01, n^2_p = .05]; see Figure 7.

4.5.3 Influence of beat perception ability

Young adults. Among the young adults, poor beat perceivers took significantly shorter strides to all stimuli [F(1, 74) = 5.89, p = .02, n^2_p = .07] as well as had a slower stride velocity [F(1, 74) = 4.1, p = .04, n^2_p = .06] compared to good beat perceivers, regardless of whether they synchronized to the beat or freely walked. There was no significant influence of beat perception ability on cadence [$F(1, 74) = 2.16$, $p = .15$, $n^2_p = .03$], see Figure 4. In regards to gait stability, there was no significant influence of beat perception ability on stride width [$F(1, 74) = .48$, $p = .49$, $n^2_p = .01$] or double support time [$F(1, 74) = .08$, $p = .77$, $n^2_p = .001$]; see Figure 5. In addition, there was no significant influence of beat perception ability on gait variability: stride time variability [$F(1, 74) = 2.19$, $p = .14$, $n^2_p = .03$], stride length variability [$F(1, 74) = .18$, $p = .68$, $n^2_p = .002$], stride velocity variability [$F(1, 74) = .02$, $p = .88$, $n^2_p < .001$], stride width variability [$F(1, 74) < .001$, $p = .99$, $n^2_p < .001$], double support time variability [$F(1, 74) = .96$, $p = .33$, $n^2_p = .01$]; see Figure 4 and Figure 5.

In addition, the ANCOVA showed no significant interactions between beat perception ability and condition, beat perception ability and instruction type, nor beat perception ability, condition, and instruction type.

Table 5 and Table 6 depict all main effects and interactions from the ANCOVA for gait speed and stability, as well as gait variability, respectively.

Older adults. Among the older adults, poor beat perceivers had a slower stride velocity to the stimuli [$F(1, 90) = 4.11$, $p = .04$, $n^2_p = .04$] compared to the good beat perceivers, regardless of whether they were synchronizing to the beat or free walking; whereas there was no influence of beat perception ability on cadence [$F(1, 74) = .40$, $p = .53$, $n^2_p = .004$], see Figure 6. In regards to gait stability, there was a significant influence of beat perception ability on double support time with poor beat perceivers showing a longer duration compared to good beat perceivers [$F(1, 90) = 3.87$, $p = .05$, $n^2_p = .04$], see Figure 7.

In addition, the ANCOVA showed no significant interactions between beat perception ability and condition, beat perception ability and instruction type, nor beat perception ability, condition, and instruction type.

Table 7 and Table 8 depict all main effects and interactions from the ANCOVA for gait speed and stability, as well as gait variability, respectively.

4.6 Comparing Change Scores to Baseline

4.6.1 Young adults. One sample t-tests showed that the change from baseline when instructed to freely walk was not a significant difference whereas the change from baseline when instructed to synchronize was a significant difference. Therefore, the poor beat perceivers, when instructed to synchronize, had faster strides to the high enjoyment music [t(20) = 2.83, p = .01], low enjoyment music [t(20) = 2.58, p = .02], and the metronome [t(20) = 3.04, p = .01] compared to baseline. In addition, the poor beat perceivers, when instructed to synchronize, had more steps per minute to the high enjoyment music [t(20) = 2.29, p = .03], low enjoyment music [t(20) = 2.70, p = .014], and the metronome [t(20) = 6.17, p = .00] compared to baseline. The good beat perceivers, when instructed to synchronize, had faster strides to the high enjoyment music [t(19) = 5.31, p = .00], low enjoyment music [t(19) = 4.72, p = .00], and the metronome [t(19) = 4.32, p = .00] compared to baseline. In addition, the good beat perceivers, when instructed to synchronize, had more steps per minute to the high enjoyment music [t(19) = 5.03, p = .00], low enjoyment music [t(19) = 3.48, p = .003], and the metronome [t(19) = 3.41, p = .003] compared to baseline. In regards to gait stability, the poor beat perceivers, when instructed to synchronize, had wider strides to the metronome [t(20) = 2.44, p = .02] compared to baseline. The good beat perceivers, when instructed to synchronize, had briefer strides to the high enjoyment music [t(19) = -3.03, p = .00], low enjoyment music [t(19) = -2.17, p = .003], and the metronome [t(19) = -2.59, p = .02] compared to baseline; see Figure 4 and Figure 5.

4.6.2 Older adults. One sample t-tests showed that the change from baseline when instructed to freely walk was not a significant difference for the poor beat perceivers whereas the differences were significant for the good beat perceivers. Therefore, the good beat perceivers, when instructed to freely walk, had faster strides to high enjoyment music [t(20) = 2.74, *p* = .01], low enjoyment music [t(20) = 2.60, *p* = .02], and the metronome [t(20) = 2.97, *p* = .007] compared to baseline. In addition, the good beat perceivers, when instructed to freely walk, had more steps per minute to the high enjoyment music [t(20) = 2.74, *p* = .01], low enjoyment music [t(20) = 2.6, *p* = .02], and the metronome [t(20) = 2.97, *p* = .01] compared to baseline. In regards to gait stability, the poor beat perceivers, when instructed to freely walk, had wider strides to the low enjoyment music [t(14) = -2.23, *p* = .04] compared to baseline. Furthermore, the change from baseline when instructed to synchronize was a significant difference for both poor and good beat perceivers. Therefore, the poor beat perceivers, when instructed to synchronize, had shorter strides to the high enjoyment music [t(13) = -3.33, *p* = .005], low enjoyment music [t(13) = -3.35, *p* = .005], and the metronome [-2.49, *p* = .03] compared to baseline. In addition, the poor beat perceivers, when instructed to synchronize, had more steps per minute to the metronome [t(13) = 3.12, *p* = .008] compared to baseline. The good beat perceivers, when instructed to synchronize, had shorter strides to the high enjoyment music [t(24) = -3.20, *p* = .004], low enjoyment music [t(24) = -3.05, *p* = .005], and the metronome [t(24) = -2.61, *p* = .01] compared to baseline. In addition, the good beat perceivers, when instructed to synchronize, had more steps per minute to the metronome [t(24) = 6.05, *p* = .00] compared to baseline. In regards to gait stability, there were no significant differences when instructed to synchronize among the poor and good beat perceivers compared to baseline; see Figure 6 and Figure 7.

Chapter 5

5 Discussion

The aim of this study was twofold. We first examined changes in gait performance as a result of subjective music enjoyment in healthy younger adults and in healthy older adults. Contradictory to our hypothesis that higher music enjoyment would alter gait parameters, there was no effect of enjoyment on gait for either the young adults or the older adults. However, there were differences in the way young adults and older adults walked to the music compared to the metronome. For example, young adults had a faster stride velocity and a shorter stride length to the music compared to metronome, whereas the older adults had a faster stride velocity to the metronome, but no differences in stride length between any of the conditions. Second, we examined how instructions to synchronize to the beat altered gait in young adults and older adults, taking into account their beat perception ability. We found different influences of synchronization between the two age groups. When the young adults were instructed to synchronize to the beat, stride velocity as well as cadence increased and double support time decreased to the music; whereas in older adults, stride velocity and cadence decreased and double support time increased to the music compared to the metronome. There were no significant interactions between beat perception ability and instruction type among young adults and older adults, thus our hypothesis that poor beat perceivers would show significantly less benefit than good beat perceivers during synchronizing compared to free walking was not supported. Younger poor beat perceivers showed less velocity, cadence, and stride length increase than good beat perceivers when synchronizing compared to freely walking. Similarly, older poor beat perceivers showed greater slowing and increased shortening of strides than good perceivers when synchronizing. However, reduced benefit on gait parameters for poor beat perceivers was not limited to the synchronized condition, hence the lack of significant interaction between beat perception ability and instruction type. These data support previous findings that beat perception ability influences gait parameter changes in response to music (Leow et al., 2014).

5.1 Enjoyment has no influence on movement vigor

Although music is often considered a rewarding stimulus, and stimulates the limbic system (Alluriet, Toiviainen, Jasskelainen, & Brattico, 2012**),** both high and low enjoyment music that participants rated as high in enjoyment and as low in enjoyment had similar effects on gait speed and balance. It is possible that our enjoyment manipulation was not strong enough, and that greater differences between enjoyed and unenjoyed music are needed to see an effect of enjoyment. However, the enjoyment difference between the conditions was numerically large (45 points on a 100-point scale), in addition to significant, and our samples were large, suggesting that an enjoyment manipulation may have to be very strong, perhaps impractically so, for an effect to be observed. Overall, the data suggest that changes in gait and balance, whether beneficial or detrimental, are not strongly influenced by enjoyment. Although enjoyment did not significantly affect gait parameters, music can shift attention away from fatigue and gait instability as a result of the pleasure of moving to the music (de Dreu et al., 2012). Therefore, optimizing music for enjoyment, even if it does not alter gait itself, may be beneficial in a rehabilitative setting, for example, in increasing adherence to the intervention. Taken in that light, it is useful that the current results suggest that enjoyment of the music does not appear to negatively affect gait parameters, thus enjoyable music may perhaps be used to enhance the experience of rhythmic auditory stimulation interventions.

5.2 Instructions to synchronize

There is inconsistency in the evidence surrounding gait improvements and whether one should synchronize one's footsteps to the beat. Dalla Bella et al. (2015) found increased stride length and gait velocity among patients with Parkinson's disease when given the instruction to synchronize, whereas Benoit, Dalla Bella, Farrugia, Obrig, Mainka, and Kotz (2014) found increased stride length with no instruction to synchronize. In the current study, the instruction to synchronize to the beat was more effective at enhancing gait velocity than the instruction to freely walk for the young adults, whereas the instruction to synchronize to the beat was less effective at enhancing gait velocity and stride length for the older adults. Therefore, the optimal instructions may depend on the age of the person receiving RAS.

Currently there is inconsistent evidence as to which type of stimulus, music or a metronome, is more beneficial to use in RAS to improve gait. Furthermore, the type of stimulus that is most beneficial may depend on instructions: previous research shows differential influences of the instruction to synchronize when walking to music compared to a metronome for both young and older adult. Styns, van Noorden, Moelants, and Leman (2007) found faster walking speeds to music than to the metronome among healthy young adults when explicitly instructed to synchronize to the musical pulse. However, de Bruin, Doan, Turnbull, Suchowersky, Bonfield, Hu, and Brown (2015) found that gait velocity, stride length, and cadence improved similarly to music compared to the metronome among healthy young adults with no explicit instruction to synchronize. Contrary to Styns et al. and de Bruin et al., the current study showed no difference in gait velocity between the music and the metronome when instructed to synchronize and faster walking speeds to music than the metronome, along with shorter strides to the metronome compared to music, when not instructed to synchronize among the young adults. In support of de Bruin et al., the current study found similar increases in cadence to the metronome compared to music among young adults, regardless of the instruction to synchronize. As for older adults, Wittwer et al. (2013) found faster gait velocity and longer stride length to music compared to the metronome as well as similar increases in cadence with instructions to synchronize. Contrary to Wittwer et al. (2013), the current study showed a faster gait velocity to the metronome compared to the music, and a similar change in stride length to the metronome as to music, among older adults, regardless of the instruction to synchronize. In addition, the current study found an increased cadence to the metronome compared to the music when instructed to synchronize.

Along with differences in speed, differences in gait variability can differ to music compared to a metronome among young adults and older adults. De Bruin et al. (2015) indicated no significant differences in gait variability between the metronome and music, however the metronome trended towards eliciting more stride time variability than the music when no explicit instructions to synchronize were given. In support of de Bruin et al. (2015), the current study showed similar changes in gait variability between the metronome and music among young adults when given no explicit instructions to synchronize. In addition, Leow et al. (2014) found no significant difference in stride time variability as well as stride length variability between the metronome and music among young adults with explicit instructions to synchronize. Similar to this, the current study showed no difference in stride length variability between music and the metronome among young adults with explicit instructions to synchronize, however, there was more stride time variability to music compared to the metronome. As for older adults, Wittwer, Webster, and Hill (2013) indicated no significant differences in stride time variability as well as stride length variability between music and a metronome among older adults when instructed to synchronize. Contrary to Wittwer et al. (2013), the current study showed more stride time variability and stride length variability to the music compared to the metronome among the older adults when instructed to synchronize.

Mulder, Berdt, Pauwels, and Nienhuis (1993) found slower walking speeds among older adults compared to younger adults when performing a cognitive calculating task while walking**.** Decker, Cignetti, Hunt, Potter, Stergiou, and Studenski (2016) increased the attentional demand of walking and found higher variability in the step length and step time variability in the older adults compared to the young adults when walking was combined with a dichotic listening task, attributed to the older adults walking at a slower speed. Thus, the dual-task of walking while listening to an auditory stimulus may increase cognitive load by shifting the attention to one's gait (Baker, Rochester, & Niewboer, 2008). Explicit instructions to synchronize to a metronome while walking can interrupt the automatic gait rhythm, increasing gait variability for both young adults (Hamacher, Hamacher, Herold, & Schega, 2016) and older adults (Baker et al., 2008). Hamacher et al. (2016) stated that older adults were more variable than the younger adults when synchronizing with the metronome. In support of this, the current study found increased gait variability among both young and old adults, with older adults showing more gait variability compared to younger adults, when instructed to synchronize. Therefore, the greater reduction in gait speed and more variability among older adults compared to young adults while synchronizing footsteps to the beat suggests that both cognitive and motor abilities are required to perform the dual task (Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008). In addition, the current study also found variability differences between stimuli among the older adults with more variability to music compared to the metronome compared to the young adults who did not show significant differences in gait variability among the stimuli.

Tapping synchronization studies indicate that the ability to track an event over time decreases throughout the lifespan, increasing the difficulty of synchronizing to a perceived beat (i.e., timing coordinated movements; McAuley, Holub, Jones, Johnston, & Miller, 2006). Therefore, the poorer gait shown among the older adults when synchronizing with the music (i.e., slower, shorter and more variable strides) may be a result of the narrow entrainment range. Thus, it may be more beneficial to instruct an older adult to walk comfortably to the music rather than to synchronize. Additionally, music may be harder for older adults to walk to due to the complex nature of the music structure (i.e., rising and falling of pitch, melody, rhythm, harmony, and tempo). Leman, Moelants, Varewyck, Styns, van Noorden, and Martens (2013) suggested that higher complexity in the musical structure and less clear beats reduce the willingness to increase step length. Since a metronome is a repetitive stimulus that may be simpler to track, it may allow for less attention to be diverted towards walking, reducing the cognitive demand and improving gait among older adults.

The effects a metronome has on gait compared to music, and the increased attention to walking when instructing the individual to synchronize, should be taken into consideration when choosing the auditory stimulus to use during RAS. Variability in gait as well as task performance can be improved by familiarizing the individual with the dual-task prior to having the individual execute the movement (Hamacher et al., 2016); as Wittwer et al. (2013) did. Older adults may benefit from practicing the dual task as a "posture second" strategy can be adopted whereby gait is sacrificed when a cognitive task is given while walking (Decker et al., 2016). This may assist with making body movements more automatic and faster rather than consciously controlled when synchronizing, reducing the attentional demand on coordinating body movements and improving gait. An outcome of this shift in attention may be a more effective and efficient motor program with more accuracy, increased speed, and optimal muscle coordination (Wulf, 2013).

Thus, patients with movement disorders can benefit from a more external focus of attention as well (Wulf, 2012).

5.3 Beat perception and gait.

An aspect of music that can influence the response to RAS is beat perception ability. When instructed to synchronize to music tempo that was 22% faster than preferred cadence, stride length shortened to increase stride velocity among poor beat perceivers (Leow et al., 2014). Leow et al. (2014) suggested that poorer beat perceivers showed slower and shorter strides when synchronizing footsteps to the beat compared to the good beat perceivers, due to a greater attentional demand. The current study found that young adults with poor beat perception increased cadence by 3-4% and shortened strides to the music by 2%. Furthermore, the older adults with poor beat perception ability tended to take shorter strides to the music when instructed to synchronize compared to the good beat perceivers; however, the shortening of strides elicited by the metronome was comparable to the good beat perceivers. Therefore, similar to Leow et al. (2014), individual differences in beat perception ability alter gait responses when synchronizing to the music; possibly because of the task difficulty for poor beat perceivers. Leow et al. (2014) suggested that embedding a metronome within music may encourage those with poorer beat perception ability to take faster and longer strides.

This notion can be beneficial when creating a rehabilitation program involving RAS, as knowing the individual's beat perception ability will allow the physical therapist to tailor the instruction type and the auditory stimulus to the patient; optimizing gait outcomes.

5.4 Limitations

Although the BAT is a reliable measure for beat perception ability that can be implemented in a rehabilitation setting, it provides a limited amount of information (Leow et al., 2014). Beat perception has been suggested to be affected by pitch, melody, harmony, and timbre perception (Fujii & Schlaug, 2013). Pitch perception deficits can influence rhythm perception in music but pitch perception was not tested here. Therefore, future work may benefit from using more in depth and comprehensive assessments of beat perception and production, such as the Beat Assessment of Auditory Sensorimotor and Timing Abilities or the Harvard Beat Assessment Test (Dalla Bella et al., 2017; Fujii & Schlaug, 2013).

We did not measure the asynchrony between footstep times and beat times which would indicate whether the participant accurately synchronized, although we did measure how accurately the cadence matched the beat rate of the music. A 0.15 change in cadence would match the 15% faster speed of the music, thus we do have an indication of how accurately participants matched their step rate to the rate of the music. Another potential limitation is that the initial baseline cadence may not be the individual's actual regular pace of walking. Certain factors such as the environment of a testing situation, focusing attention on walking, or the mood of the individual may influence their initial baseline gait measurement. Since this initial measure was used to calculate the beats per minute of the music for the rest of the session, if the participant walked unnaturally fast at baseline, then the music tempo may have been too fast to walk to once sped up by 15%. This would influence behavior when walking to either the music or metronome, especially in the older population where the ability to move at a fast speed may be reduced, as well as when instructed to synchronize to the beat. In this situation, some participants may opt to walk at half the pace of the music tempo, rather than matching the too-fast tempo. Another possible influence on speed of walking is the presence of demand characteristics, which is the tendency of the individual to respond in a way that they think fits the purpose of the experiment. Thus, the individual may act in accordance to their subjective bias. In addition, tapping synchronization studies indicate there may be multiple beat references of the auditory sequence that could be used to synchronize with.

We attempted to control the ratings given for familiarity, groove, beat salience and enjoyment with all songs being low in familiarity, high in groove, high in beat salience and either high in enjoyment or low in enjoyment; however, the songs that were rated as high in enjoyment and the eight songs rated low in enjoyment differed significantly on the other measures, with the songs high in enjoyment also having higher familiarity, groove, and beat salience ratings compared to the songs low in enjoyment. Therefore, the interpretation of an effect of enjoyment could be confounded by the changes in the other ratings, as enjoyment, familiarity, groove and beat salience are correlated with each other. However, since enjoyment had little to no effect on the gait parameters, and the fact that the ratings differed on other measures should have caused a greater effect to be observed, not obscured an effect, it is unlikely enjoyment has a reliable effect on gait.

Furthermore, information regarding fall history or cognitive ability of the healthy older adults was not collected. There is evidence of impaired motor ability in cognitively impaired older adults (Taylor et al., 2013). Those who have progressed to a later stage of dementia often require assistance as well as cues in order to walk safely and prevent falls (Clair & O'Konski, 2006). Studies that assess gait during dual-task walking (e.g., counting backwards while walking) indicate that gait speed reduces and variability increases among healthy older adults (Hausdorff & Yogev, 2006). These gait decrements continue to worsen with cognitive decline (Taylor, Delbaere, Mikolaizak, Lord, & Close, 2013) as well as increased frequency of falls (Hausdorff, Rios, & Edelberg, 2001). Thus, in future studies assessing previous falls as well as cognitive ability for older adults is recommended because these factors may influence gait. For example, assessments such as the Morse Fall Scale (MFS) and The Montreal Cognitive Assessment (MOCA) could be included to measure history of falls and cognitive ability, respectively. Furthermore, the gait response to a dual- task walking assessment can provide clinically relevant information regarding fall risk and executive function (Hausdorff et al., 2008).

There are individual differences in the amount of experience with walking while listening to music simultaneously (Franek, van Noorden, & Rezny, 2014). With the growing use of technology while walking among the young adults, listening to music while walking begins at an early age whereas the population currently over 50 years old did not have access to this type of technology at a young age. Therefore, young adults have more practice with listening to music while walking compared to older adults. This may explain the different behavioral responses when instructed to synchronize to the beat of music as the young adults would be more comfortable with the dual task and not have to allot as much cognitive demand to synchronizing. Thus, it would also be helpful to collect information regarding frequency of walking while listening to music to determine whether this has an effect on synchronizing to music.

Lastly, we increased the tempo of the music and metronome to 15% faster than participants' preferred cadence. Therefore, a higher tempo may not always result in an increased walking speed (Styns et al., 2007). First, there may be biomechanical limitations preventing the proper adjustments in gait needed to increase walking speed. In order to increase gait speed, trunk movements in the sagittal plane, such as hip flexion, as well as knee flexion increase (Mann & Hagy, 1980). Hollman Watkins, Imhoff, Braun, Akervik, and Ness (2016) indicated that older adults may be less able to alter trunk movements compared to young adults. Secondly, the older adults may not be inclined to walk at a fast speed due to the energy cost (e.g., less oxygen consumption; Waters, Lunsford, Perry, & Byrd, 1988) of walking at a faster pace. Thirdly, there may be an optimal music tempo in which elicits synchronization. Styns et al. (2007) found that, whether tapping or walking, around 120BPM elicits optimal synchronization and any increases or decreases in music tempo from the optimal range may reduce step length. Since tapping studies reveal individual differences in the perception of the beat rate (e.g., 4/4, 2/4, or 3/4) in faster music tempos, the individual may choose to walk half time to a fast music tempo.

5.5 Music, Gait Training, and Parkinson's Disease

Music can be implemented into various settings and potentially lead to long-term improvements in gait[3]. For example, music can be downloaded onto an individual's phone and then listened to with earbuds while walking outside, at the mall, or while on a treadmill. This can provide a means for safer walking as well as promote a more positive walking experience. The AmbuloSono Walking Program at the University of Calgary uses a personal music-playing device where an application called 'Gait Reminder' assists patients with movement disorders, such as Parkinson's disease, in taking larger and more consistent steps (BioMed Central, 2017). The music- playing device, an iPod, is strapped onto the individual's leg or arm and senses the changes in movement. The iPod will play enjoyable music when the individual takes larger steps and stops playing the music when steps become too small. This technique provides real-time biofeedback that activates the reward pathway enhancing motor vigor and self-motivation, allowing the individual continue the training exercises at home (Chomiak et al., 2017). With this technique, patients with Parkinson's disease were shown to increase gait speed, stride length, and the average duration of walking daily after almost a year of using the application (BioMed Cenral, 2017).

An application that plays music when the goal gait parameter is executed can be useful, not only for stride length but also for stride velocity or cadence. In this case, the tempo of music played would match the steps per minute the individual is walking at. In addition, an application that increases the speed of the music or reduces the speed of the music while the individual is listening to it would provide a dynamic walking experience where gait changes are more similar to everyday locomotion.

One hypothesized source for gait dysfunction in Parkinson's disease is an inability to adjust stride length when gait speed increases (Morris, Iansek, Matyas, & Summers, 1994a), leading to gait instability. When patients with Parkinson's disease, who are known to have poorer beat perception ability, focus on stepping in time to the speed of the metronome, stride length shortens compared to walking in absence of an auditory stimulus (Morris, Iansek, Matyas, & Summers, 1994b). This may be due to the dual task itself or a result of the stimuli tempo being played at an uncomfortable speed. For example, Williams et al. (2006) instructed patients with Parkinson's disease to synchronize footsteps to the metronome beat and found an increase in stride length when the metronome beats were 10% slower than preferred cadence as well as 10% faster than preferred cadence, however stride length shortened when the metronome was 20% faster than preferred cadence. Therefore, there may be a certain tempo range in which optimizes the ability to adjust one's stride length to the altered cadence.

Synchronizing to a strong beat within the music can also elicit faster movements shown via improvements in exercise performance as well as in rehabilitation settings (Karageorghis & Terry, 1997). Among those with Huntington's disease it has been found that when the neurological disease becomes more progressed, a metronome is more successful at eliciting movement improvements during cued and uncued walking trials compared to complex music (Thaut, Miltner, Lange, Hurt, & Hoemburg, 1999); therefore, in some cases the reverse is seen where the metronome elicits greater improvements than the music. RAS has been indicated to increase gait stability among those with Parkinson's disease as the auditory cue provides a focus of attention, whereas the older adults decrease in gait stability with an auditory cue (Baker et al., 2008).

The proposed mechanism, in a healthy brain, involves projections from the basal ganglia to the supplementary motor area (SMA). In Parkinson's disease, these projections from the basal ganglia are diminished, however the ability to entrainment to a rhythmical stimulus stays intact (McIntosh et al., 1997). Therefore, a compensatory mechanism is used involving the cerebellum. The cerebellum projects to the SMA to elicit movement in time to the auditory cue. Although there are immediate carryover effects on gait from RAS, the duration of training that will result in long-term gait improvements, and the cerebral mechanism that underlie these improvements, are still unknown. The combination of RAS with physical therapy has been shown to elicit longer lasting improvements in gait than with physical therapy alone, however since many aspects of cueing are unknown, physical therapy programs differ in the activities given; the intensity and duration of the intervention; as well as the variables measured (Rubinstein, Giladi, & Hausdorff, 2002). Since sensorimotor synchronizing includes both physical and cognitive stimulation, RAS is a promising avenue for neurorehabilitation as multiple areas of the brain are engaged (Dhami, Moreno, & DeSouza, 2015).

5.6 Concluding Statements:

The present investigation revealed novel insight that gait parameters do not alter depending on subjective musical enjoyment. This study also provides direct comparisons between healthy young adults and older adults in gait responses to RAS which has not been found prior. There were differential influences of beat perception ability and instruction type between young adults and older adults, which can potentially further research in age-associated changes in gait. These results can assist physical therapists in giving proper instructions based on an individual’s beat perception ability as well as age in order to optimize movement improvements.

Table 1: Young Adult Stimuli in Ratings Task

Song	Artist	Genre	Duration
Rockstar	Nickleback	Rock	2:01
Crazy	Unknown	Electronic music	2:30
Icky Thump	Unknown	Rock	2:36
Happy	Unknown	Rock	2:23
Merengue Mambo	Unknown	Latin	2:21
Chillout	Unknown	Electronic music	2:23
Invincible	Borgeous	Electronic music	2:30
Kraken	Knife Partyand Tom Staar	Electronic music	2:19
PLUR Police	Knife Party	Electronic music	1:26
Wolves	Digitalism	Electronic music	2:28
Helicopter	Unknown	Electronic music	2:45
ATB remember	Unknown	Ambiant music	2:18
Midnight Storm	Unknown	Ambiant music	2:17
Eye	Lucky Chomps	Rhythm and Blues	2:24
Heads or Tails	Unknown	Rock	2:17
Bar Music	Unknown	Rock	2:16
African lions	Unknown	African	1:40
Greek	Unknown	Greek	2:45
Jordan	Buckethead	Heavy Metal	2:06
Somewhere in my car	Keith Urban	Country	2:07
Do you know	Enrique Iglesias	Latin	2:11
Sunset	Unknown	Italian	2:08
Without	Lucky Chomps	Rhythm and Blues	2:52
Missy Elliott	Missy Elliot	Hip Hop	2:03
Wild	Will Smith	Hip Hop	1:47
Never Let Me Down Again	Unknown	Electronic music	1:57
Zumba Latina	Unknown	Latin	2:03
Flamenco Chill	Unknown	Ambiant music	1:55
Conmigo Pachanga	Eddie Palmieri	Latin	1:42
Muy Tranquilo	Unknown	Hip Hop	1:40
Candy rock	Unknown	Rock	1:30
Hammerstrike	Unknown	Rock	1:58

Table 2: Older Adult Stimuli in Ratings Task

Song	**Artist**	**Genre**	**Duration**
Bgmusic	Catherine Michael	Rhythm and Blues	1:52
Eye of the tiger	Lucy Chomps	Rhythm and Blues	2:24
Kus Kus	Unknown	German Folk	4:20
Zumba Latina	Unknown	Latin	2:03
Wolves	Digitalism	Electronic music	2:28
Candy Rock	Unknown	Rock	3:06
Halo	Michael Salvatori	Film music	1:33
Bryter Lyter	Nick Drake	Folk	2:15
Druid Fluid	Yo-Yo Ma, Edgar Meyer	Classical	2:17
Conmigo Pachanga	Eddie Palmieri	Latin	2:14
Bouree	Unknown	German Folk	9:14
Cripple Creek	Unknown	German Folk	7:15
Flip Flop	Unknown	German Folk	7:37
Louisiana	Unknown	German Folk	10:02
Nobles Mystic	Unknown	German Folk	6:45
Once More	Unknown	German Folk	8:58
Peach Fuzz	Unknown	German Folk	6:30
Surfing	Unknown	German Folk	5:31
The Drunk	Unknown	German Folk	4:52
Twangy	Unknown	Country	10:28
Zone	Unknown	German Folk	5:04
Albatross	Unknown	German Folk	3:00
His Hand	Unknown	German Folk	3:49
Music Magic	Unknown	German Folk	4:08
King	Unknown	German Folk	5:19
Muy Tranquilo	Unknown	Hip Hop	1:39
Merengue Mambo	Unknown	Latin	2:21
Sweet Child	Unknown	German Folk	6:42
Missy Elliott	Missy Elliott	Hip Hop	2:03
Flamenco Chill	Unknown	Latin	1:55

Midnight Storm	Unknown	Ambiant music	2:17
Somewhere in my car	Keith Urban	Country	2:07

Table 3: Repeated Measures ANCOVA Comparing Gait Speed and Stability Between Age Groups

Main Effects	Age			Stimuli			BAT perception score			Instruction Type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	**15.99**	**< .001**	**0.09**	**8.11**	**.001**	**.05**	**5.14**	**.02**	**.03**	0.25	.62	0.002
Stride Length	**8.87**	**.003**	**0.05**	.09	.83	0.001	**4.62**	**.03**	**.03**	**20.20**	**< .001**	**0.11**
Cadence	1.82	.18	0.01	**13.74**	**< .001**	**0.08**	2.16	.24	.01	1.72	.19	0.01
Stride Width	.007	.93	< .001	.12	.88	.001	0.25	.61	.002	1.03	.31	0.006
Double Support Time	**8.57**	**.004**	**0.05**	2.72	.08	.02	0.99	.32	.006	1.82	.82	< .001
Interaction Effects	Stimuli*Instruction type			Stimuli*Instruction type*Age			Stimuli*Age			Instruction*Age		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	**6.96**	**.002**	**0.04**	2.44	.10	.01	**23.43**	**< .001**	**0.13**	**9.55**	**.002**	**0.06**
Stride Length	1.33	.26	.008	0.43	.57	0.003	**7.46**	**.003**	**0.04**	**4.39**	**.04**	**0.03**
Cadence	**6.46**	**.003**	**0.04**	**3.34**	**.04**	**.02**	**10.61**	**< .001**	**0.06**	0.66	.42	0.004
Stride Width	0.32	.72	0.002	3.12	.04	.02	1.80	.17	0.01	0.22	.64	0.001
Double Support Time	**3.47**	**.04**	**0.02**	0.24	.77	0.001	**10.07**	**< .001**	**0.06**	2.61	0.12	0.02

Note: Used Greenhouse- Geisser for all gait parameters

Table 4: Repeated Measures ANCOVA Comparing Gait Variability Between Age Groups

Main Effects	Age			Stimuli			BAT perception score			Instruction Type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	**23.10**	**< .001**	**0.13**	**4.15**	**.03**	**0.02**	1.63	.20	.01	19.15	< .001	0.11
Stride Length	**18.13**	**< .001**	**0.10**	**7.25**	**.002**	**0.04**	0.27	.60	0.002	**9.46**	**.002**	**0.06**
Stride Time	**4.28**	**.04**	**0.03**	**4.79**	**.02**	**0.03**	0.004	.95	< .001	27.75	< .001	0.15
Stride Width	0.02	.88	< .001	1.30	.27	0.008	1.43	.80	< .001	3.14	.08	0.02
Double Support Time	**3.22**	**.07**	**0.02**	**6.04**	**.004**	**0.04**	1.43	.23	0.009	7.60	.007	0.05

Interaction Effects	Stimuli*Instruction type			Stimuli*Instruction type*Age			Stimuli*Age			Instruction*Age		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	0.89	.37	0.006	1.17	.29	0.007	**1.28**	**.01**	**0.03**	**9.55**	**.002**	**0.06**
Stride Length	0.52	.55	.003	2.24	.12	0.01	**1.55**	**.02**	**0.03**	**4.39**	**.04**	**0.03**
Stride Time	2.55	.09	0.02	0.54	.53	0.003	1.48	.13	0.01	0.66	.42	0.004
Stride Width	0.33	.67	0.002	0.44	.60	0.003	0.63	.50	0.004	0.22	.64	0.001
Double Support Time	1.36	.26	0.008	2.75	.07	0.02	2.37	.10	0.01	2.61	0.12	0.02

Note: Used Greenhouse- Geisser for all gait parameters

Table 5: Repeated Measures ANCOVA for Gait Speed and Stability, Young Adults

Main Effects

	Stimuli			BAT perception score			Instruction Type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	**3.47**	**.03**	**0.04**	**4.51**	**.04**	**0.06**	**11.78**	**.001**	**0.14**
Stride Length	**5.81**	**.004**	**0.07**	**5.89**	**.02**	**0.07**	.04	.84	0.001
Cadence	0.05	.94	0.001	2.16	.15	0.03	**6.21**	**.01**	**0.08**
Stride Width	.76	.47	0.01	0.48	.49	0.006	1.06	.31	0.01
Double Support Time	2.04	.13	0.03	0.08	0.77	0.001	**5.14**	**.03**	**0.06**

Interaction Effects

	Stimuli*Instruction type			Stimuli*BAT perception score			Stimuli*BAT perception score* Instruction type			BAT perception score* Instruction type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	2.35	.09	0.03	0.87	.42	0.01	0.44	.65	0.006	.62	.43	0.008
Stride Length	1.00	.36	0.01	0.95	.39	0.01	0.27	.76	0.004	.23	.63	0.003
Cadence	2.57	.08	0.03	2.07	.13	0.02	2.22	.12	0.03	.33	.57	0.004
Stride Width	1.48	.23	0.02	0.62	.54	0.008	1.06	.35	0.01	.38	.54	0.005
Double Support Time	**5.68**	**.004**	**0.07**	0.51	.60	0.007	0.03	.96	< .001	1.94	.17	0.03

Note: Used Greenhouse- Geisser for all gait parameters except for Double Support Time and Cadence where sphericity assumed was used.

Table 6: Repeated Measures ANCOVA for Gait Variability, Young Adults

Main Effects

	Stimuli			BAT perception score			Instruction Type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity CV	.69	.48	0.009	0.02	.88	< .001	**11.43**	**.001**	**0.13**
Stride Length CV	.34	.62	0.005	0.18	.68	0.002	.19	.66	0.003
Stride Time CV	1.82	.17	0.02	2.19	.14	0.03	**13.79**	**< .001**	**0.16**
Stride Width CV	2.73	.07	0.04	< .001	.99	< .001	3.12	.08	0.04
Double Support Time CV	.89	.40	0.01	0.96	0.33	0.01	.64	.42	0.009

Interaction Effects

	Stimuli*Instruction type			Stimuli*BAT perception score			Stimuli*BAT perception score* Instruction type			BAT perception score* Instruction type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity CV	.09	.88	0.001	0.17	.80	0.002	0.59	.59	0.006	.41	.53	0.005
Stride Length CV	.47	.54	0.006	0.28	.65	0.004	0.71	.71	0.003	.05	.82	0.001
Stride Time CV	2.10	.13	0.03	1.97	.14	0.03	0.32	.32	0.01	.50	.48	0.01
Stride Width CV	.08	.91	0.001	0.57	.55	0.008	1.95	.15	0.03	.58	.45	0.003
Double Support Time CV	.60	.52	0.008	0.39	.64	0.005	0.54	.55	0.007	.39	.53	0.01

Note: Used Greenhouse Geisser for all gait parameters

Table 7: Repeated Measures ANCOVA for Gait Speed and Stability, Older Adults

Main Effects

	Stimuli			BAT perception score			Instruction Type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	**25.8**	**< .001**	**0.22**	**4.11**	**.04**	**0.04**	**8.6**	**.004**	**0.09**
Stride Length	1.84	.161	0.02	3.17	.08	0.03	**24.77**	**<.001**	**0.22**
Cadence	**21.32**	**< .001**	**0.19**	0.40	.53	0.004	0.08	.771	0.001
Stride Width	1.64	.19	0.02	2.97	0.08	0.03	0.63	.43	0.007
Double Support Time	**9.98**	**< .001**	**0.10**	**3.87**	**0.05**	**0.04**	1.56	.21	0.02

Interaction Effects

	Stimuli*Instruction type			Stimuli*BAT perception score			Stimuli*BAT perception score* Instruction type			BAT perception score* Instruction type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity	**6.72**	**.002**	**0.07**	1.28	0.28	0.01	0.07	.93	0.001	1.39	.24	0.01
Stride Length	0.05	0.95	0.001	0.06	0.94	0.001	0.23	.79	0.003	1.27	.26	0.01
Cadence	**8.19**	**<.001**	**0.08**	1.48	.23	0.02	0.16	.85	0.002	0.1	.75	0.001
Stride Width	1.97	.143	0.02	0.3	.74	0.003	0.18	.83	0.002	2.02	.16	0.02
Double Support Time	1.18	0.31	0.01	6.81	.51	0.008	0.05	.95	0.001	0.87	0.35	0.01

Note: Used Greenhouse- Geisser for all gait parameters except for Stride Width where sphericity assumed was used.

Table 8: Repeated Measures ANCOVA for Gait Variability, Older Adults

Main Effects

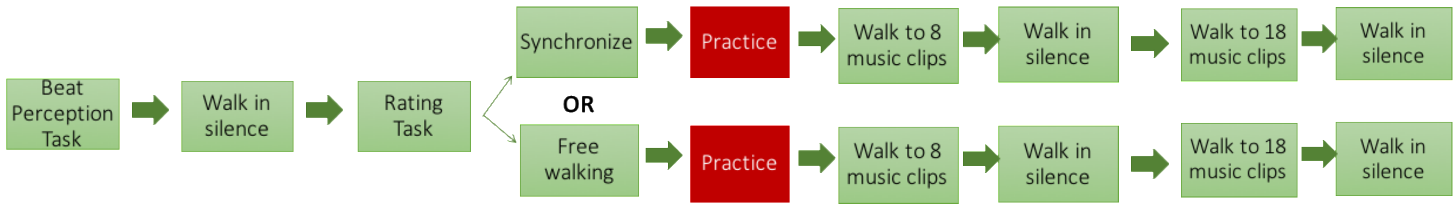
	Stimuli			BAT perception score			Instruction Type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity CV	**7.39**	**.004**	**0.08**	2.49	.12	0.03	**18.76**	**< .001**	**0.17**
Stride Length CV	**11.64**	**< .001**	**0.11**	.58	.45	0.006	**18.18**	**< .001**	**0.17**
Stride Time CV	**5.24**	**.02**	**0.05**	1.11	.29	0.01	**16.47**	**< .001**	**0.15**
Stride Width CV	.30	.68	0.003	0.85	.42	0.007	0.12	.73	0.001
Double Support Time CV	**9.63**	**< .001**	**0.10**	0.33	0.57	0.004	**14.65**	**< .001**	**0.14**

Interaction Effects

	Stimuli*Instruction type			Stimuli*BAT perception score			Stimuli*BAT perception score* Instruction type			BAT perception score* Instruction type		
Gait Parameter	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p	F	*p*	n^2p
Stride Velocity CV	1.39	.25	0.01	0.06	.86	0.001	.26	.66	0.003	1.42	.24	0.02
Stride Length CV	2.33	.11	0.02	0.35	.66	0.004	0.36	.65	0.004	.04	.84	< .001
Stride Time CV	1.58	.21	0.02	.01	.96	< .001	.08	.85	0.001	1.23	.27	0.01
Stride Width CV	.79	.42	0.009	0.05	.92	0.001	2.70	.08	0.03	.60	.44	0.007
Double Support Time CV	**4.91**	**.01**	**0.05**	0.03	.96	< .001	0.42	.63	0.005	.02	.88	< .001

Note: Used Greenhouse Geisser for all gait parameters except for Stride Time where sphericity assumed was used.

Figure 1: Procedure



Note: After completing the beat perception task, baseline preferred walks in silence, and ratings task, participants were given either the instruction to synchronize to the beat or to freely walk to the music. Then, participants walked to two music clips before walking to 18 music clips subjectively rated.

Figure 2: Correlations between Beat Perception Ability and Beat Production

Young Adults Older Adults

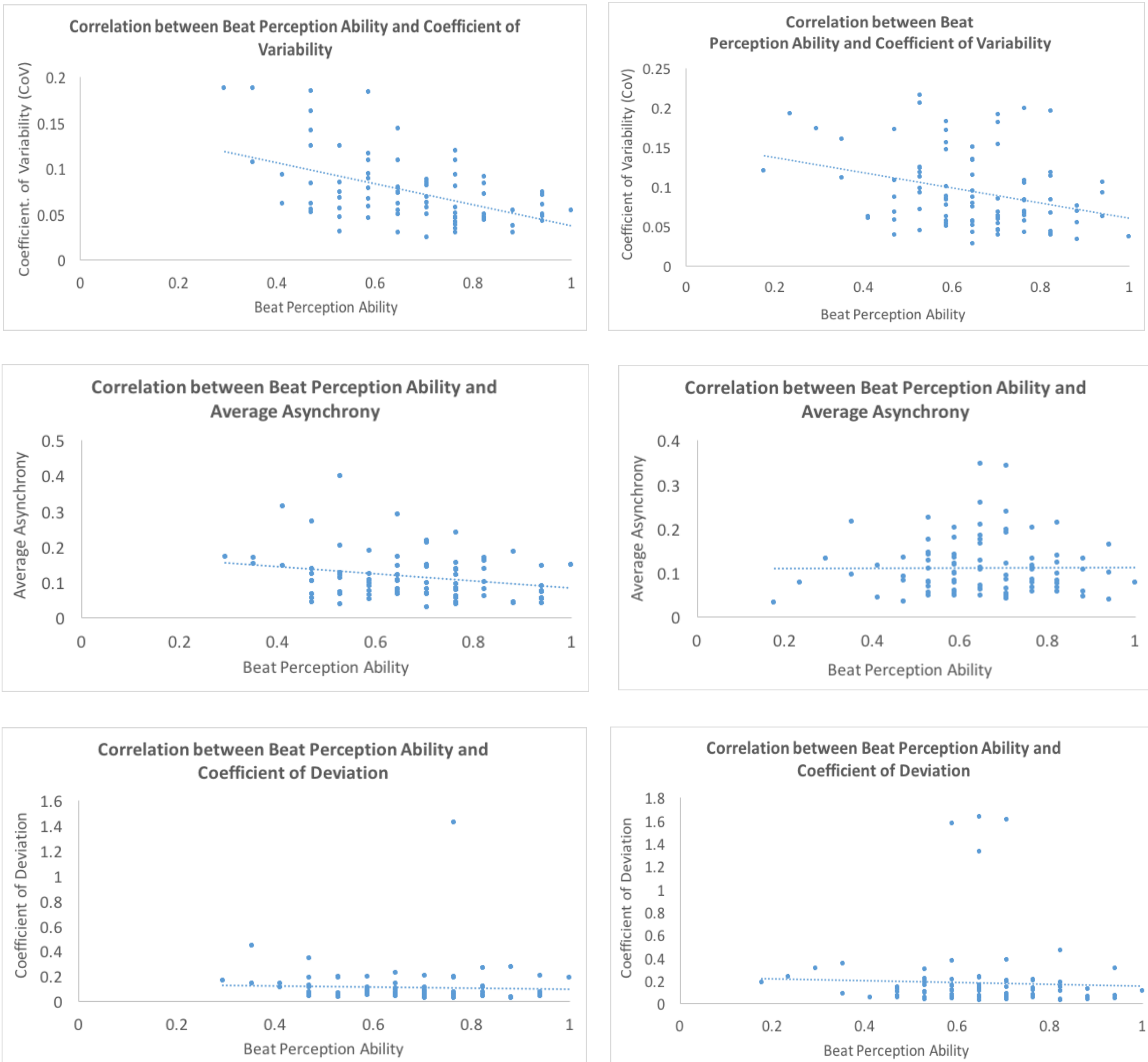
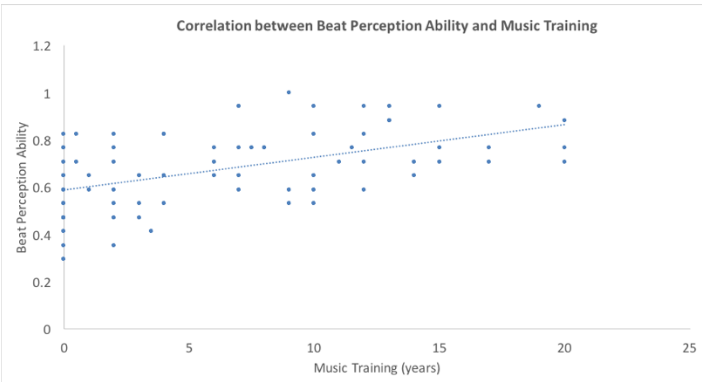
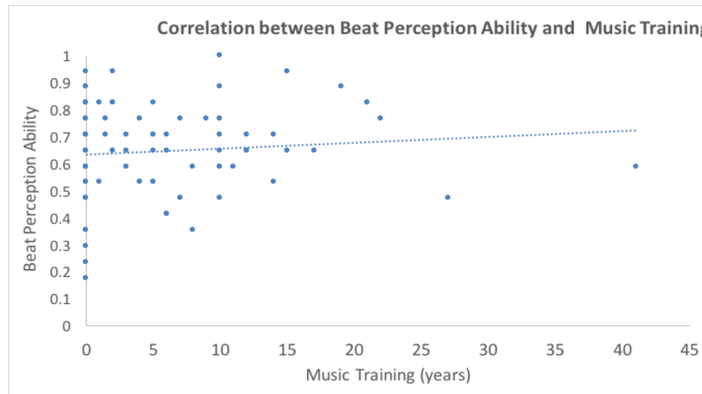


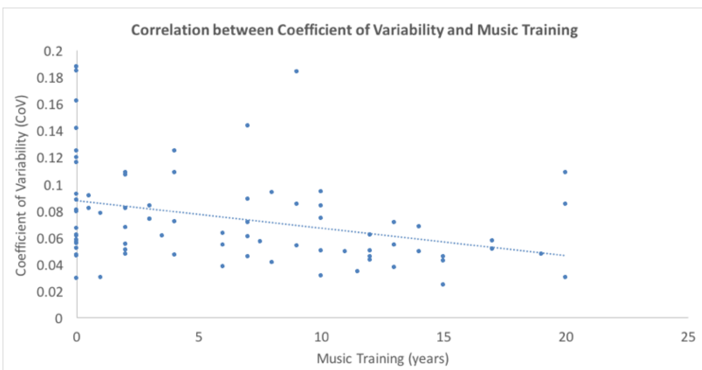
Figure 3: Correlations between Music Training, Beat Perception Ability, and Tapping Variability

Young Adults

Older Adults







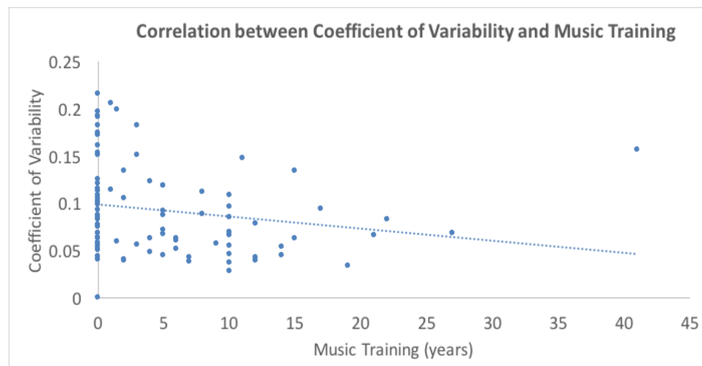
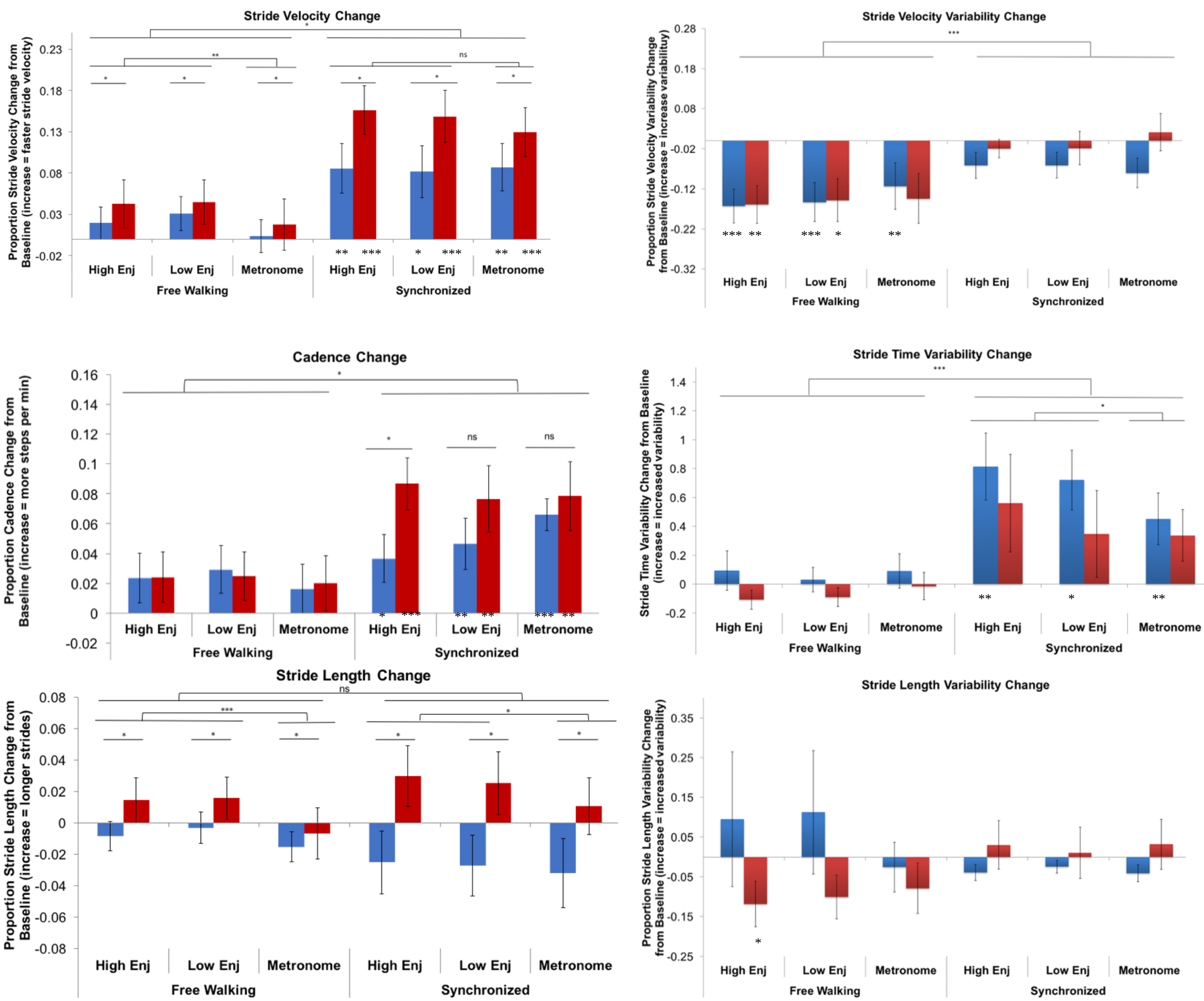


Figure 4: Change from Baseline in Young Adult Gait Speed and Variability

Gait Speed Change

Gait Variability Change

Poor beat perceivers
Good beat perceivers



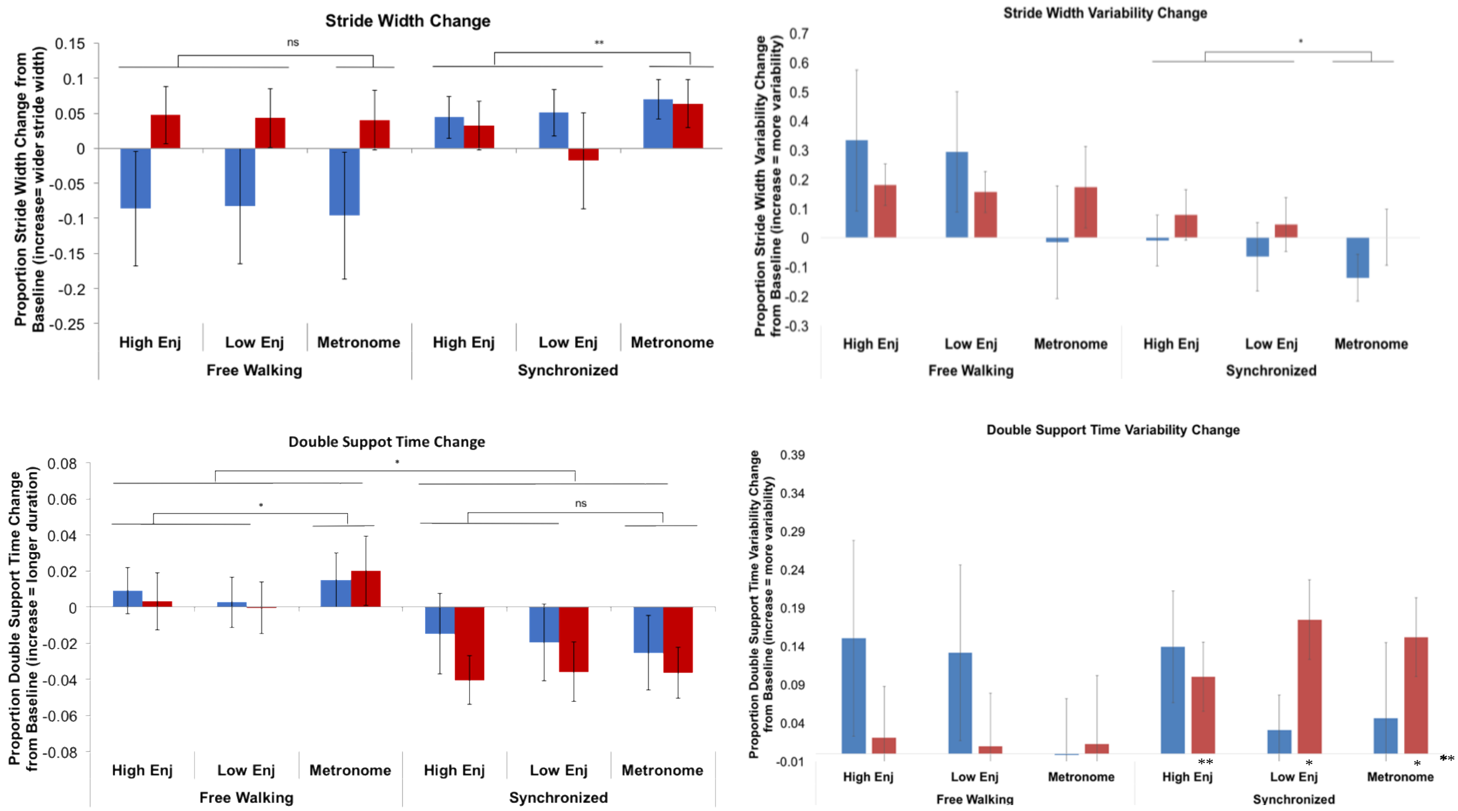
Note: *** = significant at the p = .001 level ** = significant at the p = .01 level; * = significant at the p = .05 level. Graphs on the left indicate the main effects of instruction type and beat perception ability, as well as the interaction effects between the conditions and instruction for gait speed. Graphs on the right indicate the main effects of instruction type for the corresponding gait variability parameters. Asterisks (*) under the bars indicate significant changes from baseline.

Figure 5: Change from Baseline in Young Adult Gait Stability and Variability

Gait Speed Change

Gait Variability Change

Poor beat perceivers
Good beat perceivers

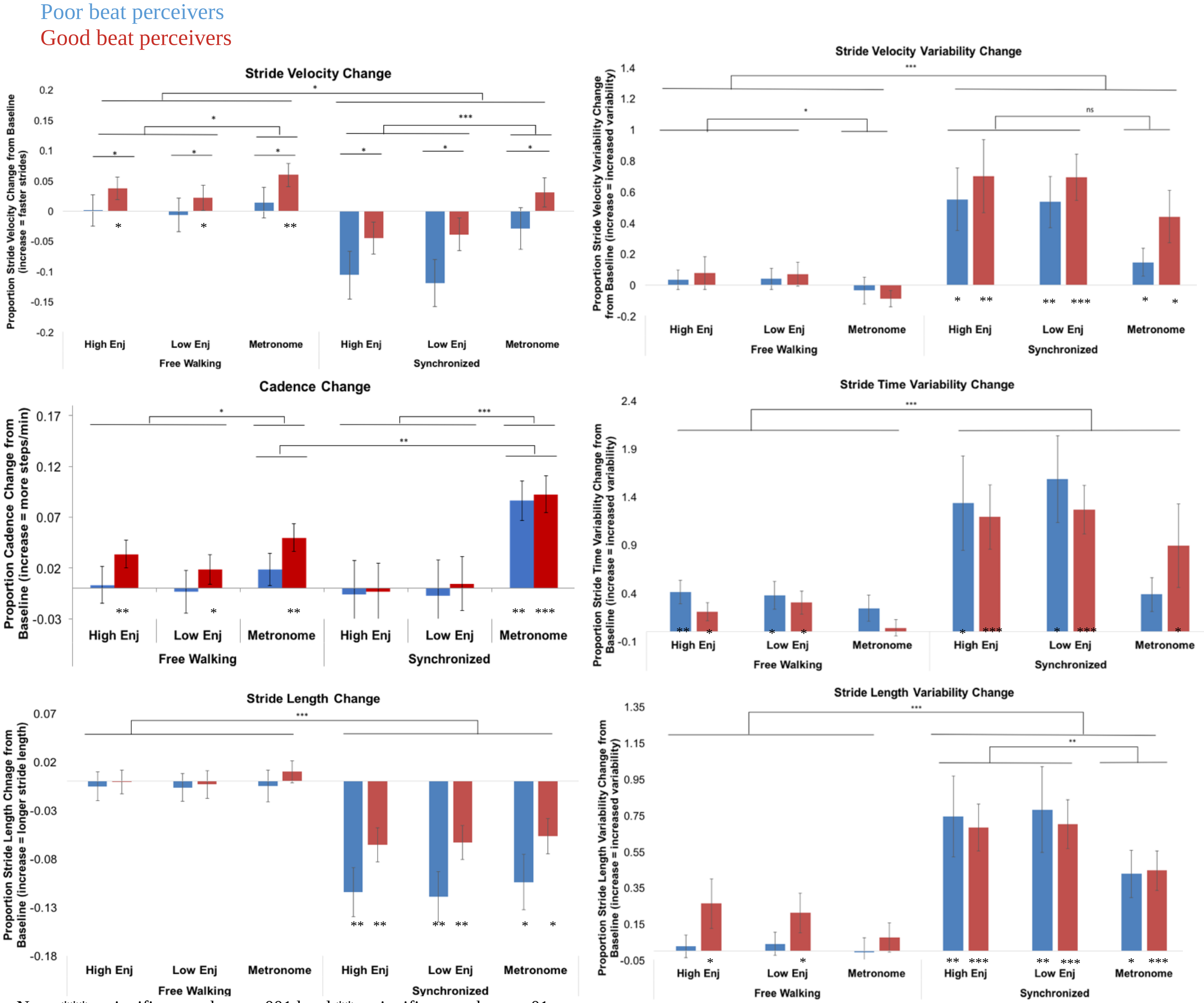


Note: *** = significant at the *p* = .001 level ** = significant at the *p* = .01 level; * = significant at the *p* = .05 level. Graphs on the left indicate the main effect of instruction type for double support time, as well as the interaction effects between the conditions and instruction type for stride width and double support time. Graphs on the right indicate the interaction effects between the conditions and instruction type for the corresponding gait variability parameters. Asterisks (*) under the bars indicate significant changes from baseline.

Figure 6: Change from Baseline in Older Adult Gait Speed and Variability

Gait Speed Change

Gait Variability Change



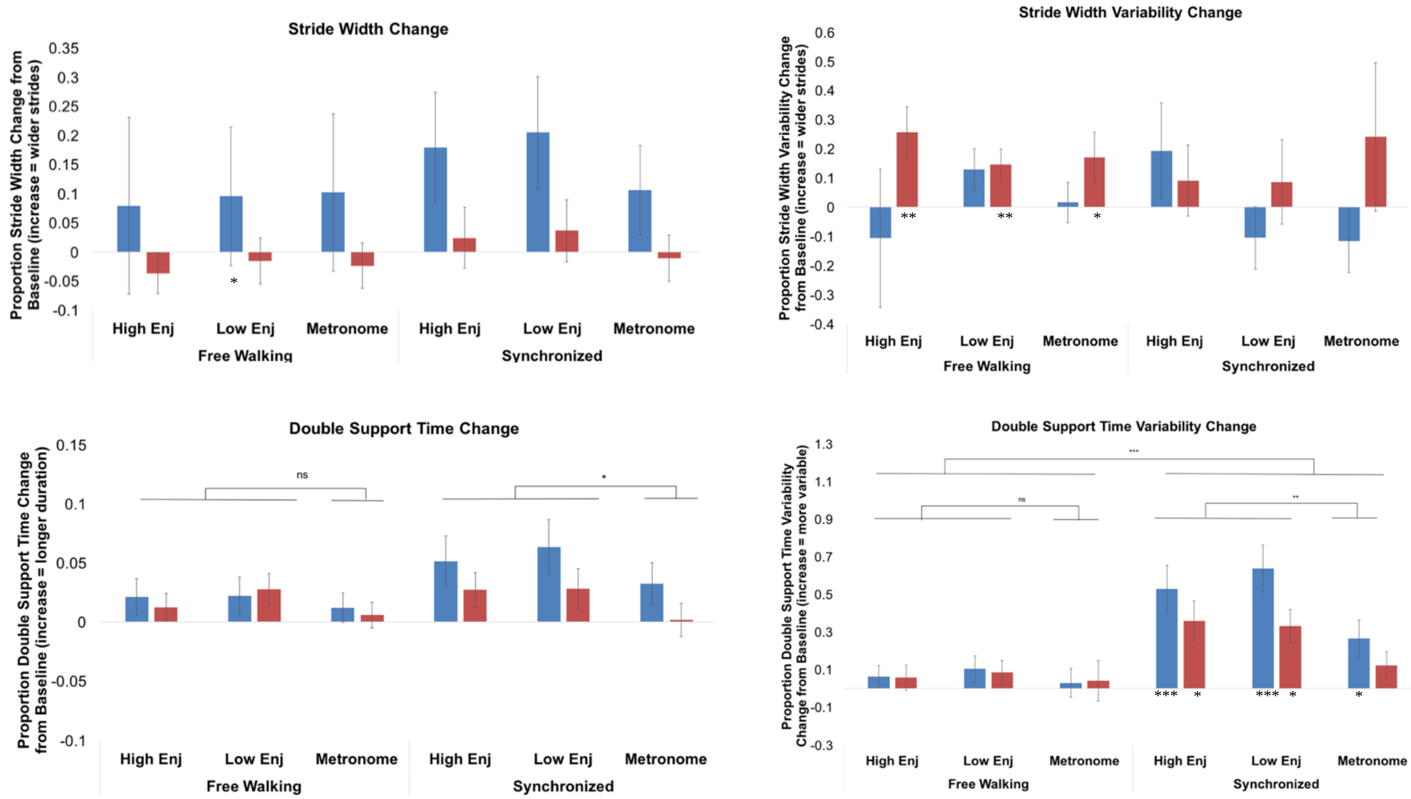
Note: *** = significant at the p = .001 level ** = significant at the p = .01 level; * = significant at the p = .05 level. Graphs on the left indicate the main effects of instruction type and beat perception ability, as well as the interaction between the conditions and instruction for stride velocity and stride length. Graphs on the right indicate the main effects of instruction type as well as the interaction effects between the conditions and instruction type for the corresponding gait variability parameters. Blue bars are poor beat perceivers and red bars are good beat perceivers. Asterisks (*) under the bars indicate significant changes from baseline.

Figure 7: Change from Baseline in Older Adult Gait Stability and Variability

Gait Stability Change

Gait Variability Change

Poor beat perceivers
Good beat perceivers



Note: *** = significant at the $p = .001$ level ** = significant at the $p = .01$ level; * = significant at the $p = .05$ level. Graphs on the left indicate the interaction effect between the conditions and the instruction type for double support time. Graphs on the right indicate the main effects of instruction type as well as the interaction effect between the conditions and instruction type for the corresponding gait variability parameter. Stride width and stride width variability did not have any significant main effects or interactions effect. Asterisks (*) under the bars indicate significant changes from baseline.

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Appendix A: Ethics Board

Western Research

Western University Non-Medical Research Ethics Board
NMREB Annual Continuing Ethics Approval Notice

Date: March 09, 2016
Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,Western University

NMREB File Number: 106385
Study Title: Behavioral studies of rhythm and music perception
Sponsor: Natural Sciences and Engineering Research Council

NMREB Renewal Due Date & NMREB Expiry Date:
Renewal Due -2017/02/28
Expiry Date -2017/03/30

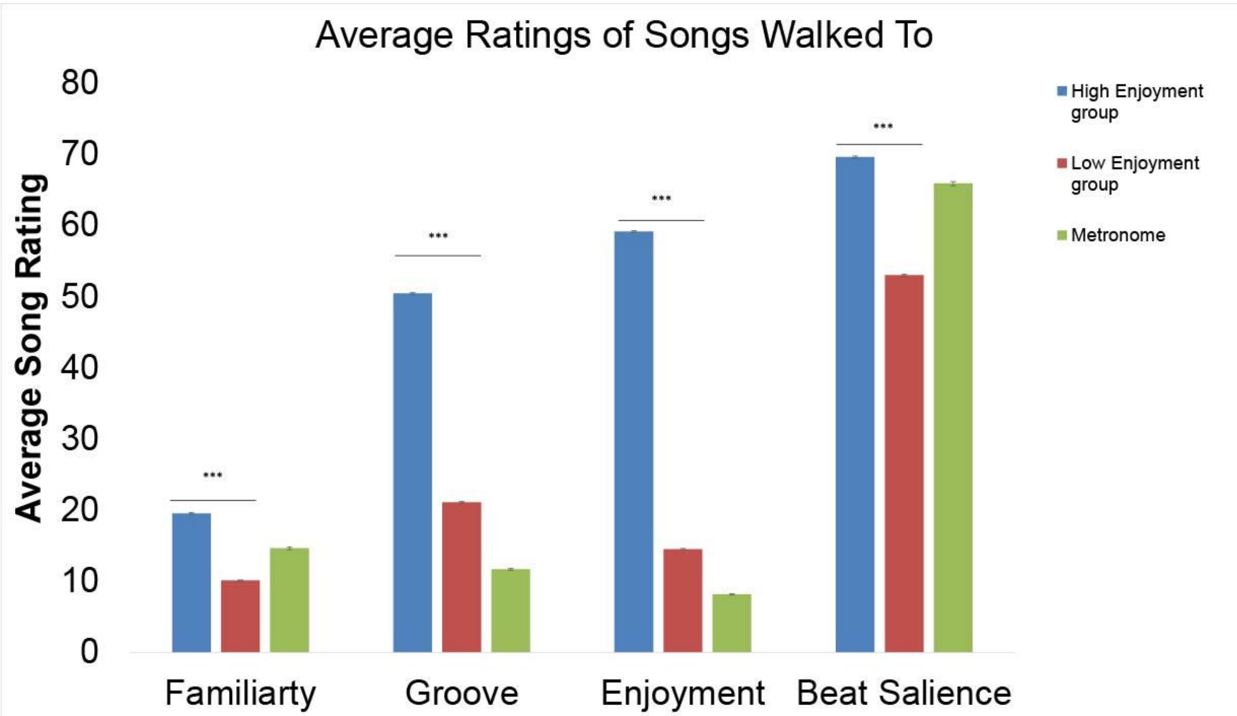
The Western University Non-Medical Research Ethics Board (NMREB) has reviewed the Continuing Ethics Review (CER) form and is re-issuing approval for the above noted study.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), Part 4 of the Natural Health Product Regulations, the Ontario Freedom of Information and Protection of Privacy Act (FIPPA, 1990), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Appendix B of Songs Walked To



Note: *** significant difference at the *p* = .001 level

Curriculum Vitae

Name: Brittany Roberts

Post-secondary Education and Degrees

Brescia University College
London, Ontario, Canada
2011-2015
B.A. Honors Double Major: Kinesiology and Psychology

Western University
London, Ontario, Canada
2015-2017
MSc Neuroscience

Honours and Awards:

Dr. Pat Devolder Award
2013
Highest mark of returning students in Psychology

Brescia Entrance Scholarship
2011-2015
Maintaining an >80 average

Nova Scotia Graduate Scholarship
2017-2019

Related Work Experience:

Teaching Assistant (2800E)

Western University

2015-2017

Tutor

Autism Ontario

2015-2017