7-30-2019 2:30 PM

Optimizing Gait Outcomes in Parkinson's Disease with Auditory Cues: The Effects of Synchronization, Groove, and Beat Perception Ability

Emily A. Ready
The University of Western Ontario

Supervisor
Grahn, Jessica A.
The University of Western Ontario Joint Supervisor
Holmes, Jeffrey D.
The University of Western Ontario

Graduate Program in Health and Rehabilitation Sciences
A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

Abstract

This dissertation explores a common, rehabilitative strategy for mitigating gait impairments in Parkinson's disease (PD) called Rhythmic Auditory Stimulation (RAS). The effects of this intervention on gait in PD are well documented but highly variable, which poses difficulty for appropriate therapeutic application. Part of this variability may be related to individual musical abilities, such as beat perception accuracy, as most RAS interventions involve synchronizing with a beat. However, music is complex and variable. Therefore, factors inherent in the music itself may play a role in these differences, such as how much the music makes you want to move (groove) or how familiar it is. The studies in this thesis address these questions by examining the effects of different musical features (e.g., groove, familiarity) in auditory stimuli on the gait of different populations (younger adults, older adults, people with PD). The immediate effects of instructions to synchronize or to walk freely to the auditory stimuli on spatiotemporal gait parameters were compared between those with good beat perception and with poor beat perception in each of the populations.

This research supports overall that high groove music and metronome cues have markedly different effects on spatiotemporal gait parameters than low groove cues, and that low groove cues have the potential to hinder spatial and temporal gait parameters. This indicates that music in RAS should be carefully assessed before use. This thesis also supports that synchronizing to RAS may be helpful to maximize the effects of cueing on temporal gait parameters across healthy adults and the PD group. However, these studies also highlight the various ways in which synchronizing can potentially compromise gait (e.g., shortening strides, increasing variability) and that this is not necessarily dependent on how well one can find a musical beat. Further research is required to understand what additional factors can be manipulated to best individualize music-based RAS for optimal gait management in clinical populations.

Keywords

Parkinson's disease, gait, rhythmic auditory stimulation, auditory cueing, beat perception, synchronization, groove, music

Summary for Lay Audience

This dissertation explores a common therapy for managing walking patterns in Parkinson's disease (PD) called Rhythmic Auditory Stimulation (RAS). Clinically implementing RAS can be challenging, as walking patterns do not always change consistently with RAS. Many RAS interventions involve people walking with the beat in music, therefore individual musical abilities (such as how well a person can find a musical beat) may contribute to this variability. However, music itself is complex and variable. Therefore, factors inherent in the music itself may play a role in these differences, such as how much the music makes you want to move (groove), or how familiar it is. The studies in this thesis address these questions by examining the effects of different musical features (e.g., groove, familiarity) in music on the walking patterns of different groups (younger adults, older adults, people with PD). The immediate effects of instructions to synchronize or to walk freely to the music on walking patterns were compared between those with good beat perception and with poor beat perception in each of the groups.

This research supports overall that high groove music and metronome cues have markedly different effects on walking patterns than low groove cues, and that low groove cues have the potential to hinder how people walk. This indicates that music in RAS should be carefully assessed before use. This thesis also supports that synchronizing to RAS, or walking in time to the beat, might help people to adapt their walking patterns. Importantly, these studies also highlight that synchronizing can potentially compromise how a person walks (e.g., taking short steps, fluctuating step length and speed) and that this is not necessarily dependent on how well one can find a musical beat. Further research is required to understand what additional factors can be manipulated to best individualize music-based RAS for the most optimal walking patterns in clinical populations.

Co-Authorship Statement

All data chapters were completed in collaboration with, and under the supervision of, Drs. Jessica Grahn and Jeffrey Holmes. Chapters 3-5 will be submitted for publication. Drs. Jessica Grahn and Dr. Jeffrey Holmes will be co-authors.

Dr. Lucy McGarry contributed to experimental design of Study 1 (Chapter 3).

For Chapter 5, Dr. Andrew Johnson provided input on statistical analyses. Dr. Mary Jenkins provided input on clinical measurements and study recruitment.

Acknowledgments

In completion of my dissertation, I would like to thank Drs. Jessica Grahn and Jeffrey Holmes for their endless guidance, support, and patience during these challenging past five years. I will be forever grateful to have had two supervisors that strive to be such exceptional mentors and teachers. Thank you.

Dr. Mary Jenkins and Dr. Andrew Johnson provided their valuable input during the project development and analysis stages of my dissertation. I am grateful to have had two committee members who are so overtly passionate about what they do, about sharing their knowledge, and who so kindly expressed an open door policy. In addition, I owe Mary endlessly for welcoming me into her clinic and for sharing with me her clinical expertise.

I am particularly grateful for the many Grahn Lab research assistants without whom this research would not have continued smoothly during the clinical years of this combined program, in particular to Alexis MacIntyre and Shaily Brahmbhatt. Additionally, I am thankful for all the knowledge, advice, and encouragement received from the exceptional graduate students and post-doctoral fellows in this Lab. I owe particular thanks to Dr. Lucy McGarry, whose guidance in the initial stages of my work was crucial.

I am thankful to the Parkinson Society of Southwestern Ontario and Rock Steady Boxing for graciously allowing me to recruit participants at their events and to the Parkinson's community that participated in this research. I can never thank you enough for your time and for sharing your experiences with me.

Last, but not least, I owe so much of this accomplishment to the people in my personal life who have supported me on this journey:

My East Coast friends and family have been endlessly supportive, patient, and encouraging. I owe a debt of gratitude to my incredible parents and sisters. Thank you for supporting me in every step of my academic career (even when I didn't call home enough), for being an unconditional sounding board, and for always encouraging me to do what I love.

To the friends that have become family in Ontario: Research can be isolating experience, but the friendships and working relationships I've built here have given me more support than I ever anticipated. Each of you motivates me to be a better person and academic, and for that I am grateful.

And to Jeff Martin: Thank you for always having the perfect balance of grounding me, pushing me to achieve my goals, and patiently supporting me during the most difficult part of this process.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ANOVA	Analysis of variance
BAI	Beck Anxiety Inventory
BAT	Beat Alignment Test
BDI	Beck Depression Inventory
BG	Basal ganglia
BPM	Beats per minute
cm	Centimeters
CV	Coefficient of variation
DA	Dopamine
DBS	Deep brain stimulation
DLST	Double-limb support time
DV	Dependent variable
Fmri	Functional magnetic resonance imaging
ft	Foot
GABA	Gamma-aminobutryic acid
GMSI	Goldsmith Musical Sophistical Index
Gpe	Globus pallidus externa
Gpi	Globus pallidus interna
L-dopa	Levodopa
m	Meter
MATLAB	Matrix Laboratory
MDS-UPDRS III	Movement Disorder Society Unified Parkinson's Disease Rating Scale Motor Subscale
MEP	Motor-evoked potential
Min	Minute
MOABI	Monoamine oxidase-B inhibitors
PD	Parkison's disease
PKMAS	Protokinetics Movement Analysis Software
PMC	Premotor cortex
QOL	Quality of life
RAS	Rhythmic auditory stimulation
SAS	Starkstein Apathy Scale
Sec	Seconds
SMA	Supplementary motor area
SNc	Substantia nigra pars compacta
SNr	Substantia nigra pars reticulate
STN	Subthalamic nucleus
TMS	Transcranial magnetic stimulation
TUG	Timed-Up-and-Go Test

List of Appendices

Chapter 1

1 General Introduction

Parkinson's disease (PD) is a degenerative movement disorder caused by neurological changes in the basal ganglia (Schapira, 2009). Most motor symptoms are treated with pharmaceutical interventions (e.g., dopamine replacement therapy), but many symptoms persist and/or become unmanageable with medication in later disease stages (Fahn, 1999; Fahn et al., 2004; Hung & Schwarzschild, 2014). For this reason, complementary therapies that target residual symptoms (such as musically cued gait training) are employed among allied health professionals.

This dissertation explores a common, non-pharmaceutical strategy for mitigating gait impairments in PD called Rhythmic Auditory Stimulation (RAS). This technique provides a safe alternative that poses minimal side effects, is low cost, and actively engages the user. The effects of this intervention on gait in PD are well documented but highly variable, which poses difficulty for appropriate therapeutic application (Ghai, Ghai, Schmitz, & Effenberg, 2018; Lim et al., 2005; Spaulding et al., 2013). Part of this variability may be related to individual musical abilities among surveyed patients, such as their ability to accurately sense a beat, as most RAS interventions involve synchronizing with a beat (Dalla Bella et al., 2017; Leow, Parrott, & Grahn, 2014). However, music is complex and variable. Therefore, factors inherent in the music itself may play a role in these differences, such as how much the music makes you want to move, or how familiar it is (Leow, Rinchon, & Grahn, 2015). The studies in this thesis address these questions by examining the effects of musical beat perception ability as well as groove (how much music makes you want to move), and familiarity on gait patterns in younger adults, older adults without PD, and people living with PD.

1.1 Parkinson's Disease Background

1.1.1 Prevalence & Burden

In Canada, approximately 100,000 people are living with PD, 85% of whom are over the age of 65 (Health Canada & Parkinson Society Canada, 2003). By 2030, nearly 25% of the Canadian population is anticipated to fall into this age group, which is expected to cause a

significant rise in the incidence of PD (Canadian Institute for Health Information, 2007; Health Canada & Parkinson Society Canada, 2003). Furthermore, PD is the second most common neurodegenerative condition following only after Alzheimer's (Shulman, De Jager, & Feany, 2011). PD accounts for 1.1% of all Disability Adjusted Life Years in Canada, 72.2% of which are lost due to disability instead of mortality (Health Canada & Parkinson Society Canada, 2003).

1.1.2 Neurological Movement Disorder

PD is a neurological condition caused by degeneration of dopamine producing neurons within the motor areas of the brain. Specifically, PD is due to depletion in dopaminergic neurons in the substantia nigra which impacts the quality of voluntary and controlled movement (Schapira, 2009). The condition is progressive and leads to increasingly severe motor symptoms over time. In later disease stages, neurodegeneration expands to additional non-dopaminergic regions of the brain, often resulting in psychiatric symptoms, sensory anomalies, and autonomic dysfunction (Schapira, 2009; Sethi, 2008). PD is predominantly diagnosed in the elderly, with an average age of onset in the mid to late 60s (Inzelberg, Schechtman, & Paleacu, 2002).

1.1.3 Symptoms

PD is characterized by four cardinal symptoms: resting tremor, bradykinesia, rigidity, and postural instability (Jankovic, 2008). Resting tremor and bradykinesia are two of the most common and easily recognized symptoms of PD. Resting tremor typically manifests unilaterally (Farrer, 2006) in the extremities but may also be experienced as an "inner tremor" that is not visible to an observer. Bradykinesia manifests as slowness of movement due to problematic planning and execution of movement (Grafton, 2004; Ruiz, Catalán, & Carril, 2011). An additionally common yet less noticeable symptom is rigidity and is experienced as stiffness or resistance of the limbs. Rigidity often results in pain that may be mistaken for other conditions such as arthritis (Jankovic, 2008; Ruiz et al., 2011). Finally, the fourth cardinal symptom is postural instability. Postural instability is one of the most common causes of falls and injuries among this population due to decreased postural control and, consequently, decreased balance (Jankovic, 2008; Kim, Allen, Canning, & Fung, 2013).

In addition to the most well-known symptoms of the condition, PD also often results in additional motor symptoms, sensory symptoms and psychological/cognitive symptoms. Examples of other motor symptoms are gait disturbances (i.e., freezing of gait, decreased step length, festination) and speech and swallowing difficulty (i.e., dysarthria, hypophonia, and dysphagia) (Jankovic, 2008). Also common among those with PD are sensory and perceptual abnormalities such as olfactory disturbance (e.g., loss of smell) and visual dysfunction (e.g., altered colour vision, hallucinations) (Jankovic, 2008; Patel, Jankovic, & Hallett, 2014; Zhu et al., 2016). Finally, PD may result in an array of neuropsychiatric symptoms such as dementia, depression, sleep disturbances, and anxiety (Sethi, 2008).

1.2 Neurological mechanisms of PD

1.2.1 Basal Ganglia Pathways

The basal ganglia (BG) are clusters of nuclei deep within the brain that facilitate neural communication about motor functions. The basal ganglia can be divided into four components: the striatum, the globus pallidus, the subthalamic nucleus (STN) and the substantia nigra (Yelnik, 2002). The striatum is a major input station for the BG and is comprised of two nuclei called the caudate nucleus and the putamen (Widnell, 2005). The striatum receives information from many areas, including the cerebral cortex, the thalamus, the amygdala and the substantia nigra. The cortex is one of the dominant sources of information input (Wall, De La Parra, Callaway, & Kreitzer, 2013; Yelnik, 2002), and information can be motor, oculomotor, associative or limbic depending on the cortical region of origin (Widnell, 2005). The striatum serves as a starting point for two pathways within the basal ganglia that help to integrate information from the cerebral cortex and the thalamus. The direct pathway involves the striatum projecting gamma-aminobutyric acid (GABA) and substance P neurotransmitters directly to the globus pallidus interna (GPi) and the substantia nigra pars reticulate (SNr), which then project to the thalamus (Gupta, 2002). By projecting inhibitory neurotransmitters, inhibitory signals to the motor cortex are reduced, therefore creating an excitatory motor effect (DeLong, 1990). Similarly, the indirect pathway starts at the striatum but instead projects GABA and enkephalin to the globus pallidus externa (GPe), which then projects to the subthalamic nucleus (STN). From there, the STN projects glutamate

to the GPi and the SNr, creating an excitatory effect on the inhibitory signals. As such, inhibitory projections to the thalamus and motor cortex are increased and movement is decreased (DeLong, 1990; Gupta, 2002).

1.2.2 Dopamine and other Neurotransmitter Involvement

These direct and indirect pathways are modified and balanced by dopamine (DA), which is a neurotransmitter highly concentrated in the substantia nigra pars compacta (SNc). The SNc is a main production area for dopamine, which is projected from the SNc to the striatum, the globus pallidus and the STN. Dopaminergic terminals from the SNc synapse on striatal neurons in both pathways (Yelnik, 2002), creating an excitatory effect for the direct pathway at D1 receptors and an inhibitory effect on the indirect pathway at D2 receptors. It is estimated that clinical symptoms do not manifest until 50-60% of dopamine within the substantia nigra has been lost. (Schapira, 2009). Neurodegeneration in PD is not limited to the BG or to DA neurotransmitters. As the disease progresses, DA deficiency is later accompanied by degeneration of other neurotransmitters such as norepinephrine, acetylcholine, and serotonin (Macphee & Stewart, 2012; Sethi, 2008). This non-dopaminergic degeneration is understood to be one of the main causes of non-motor symptoms in PD. For instance, depletion of acetylcholine in the nucleus basalis of Meynert has been demonstrated to result in cognitive impairments. Similarly, degeneration of norepinephrine in the locus coeruleus may result in hallucinations and psychosis (Macphee & Stewart, 2012; Sethi, 2008)

1.3 Etiology

Presently, there is no consensus in the literature on the causes of dopaminergic cell loss in PD (de Lau & Breteler, 2006). In the past, PD has been viewed as having mainly an environmental etiology (e.g., pesticide and metals exposure, head trauma); however, the role of both genetics and the environment are now gaining recognition as factors that may interact and lead to the development of PD (Lai, Marion, Teschke, & Tsui, 2002; Shulman et al., 2011). A “multiple hit hypothesis” is now largely accepted, suggesting that people may be born with a genetic susceptibility to PD but will not develop the condition without aggravation by an environmental factor (de Lau & Breteler, 2006; Farrer, 2006).

1.4 Treatment

1.4.1 Medication

There is no treatment of PD that can stop or slow the progression of the condition. Nevertheless, there are treatment options that help decrease the effects of certain symptoms and reduce the impact they may have on a person's quality of life (QOL). The primary treatment for PD is DA replacement therapy using levodopa (L-Dopa), a dopamine precursor (Fahn, 1999; Fahn et al., 2004). L-Dopa is often prescribed in combination with medications such as carbidopa or benserazide. However, in earlier stages or among younger patients, alternative treatments may involve dopamine agonists and monoamine oxidase-B inhibitors (MOABI) to delay the use of levodopa therapy (Fox et al., 2018). PD is often initially treated with dopamine agonists, but as the disease progresses or the patient ages it requires the integration of/transition to levodopa. Unfortunately, DA replacement therapies are minimally effective for certain PD symptoms, such as gait impairments, and eventually lead to aversive side effects including dyskinesias and motor fluctuations (Fahn, 1999; Hung & Schwarzschild, 2014). For this reason, there is increasing interest in adjunct therapies that may improve symptom management, such as music or rhythm to manage outstanding gait problems.

1.4.2 Deep Brain Stimulation

An additional form of treatment for PD is deep brain stimulation (DBS), which involves the implantation of electrodes within the brain (Limousin & Martinez-Torres, 2008). These therapies are used primarily when functional ability is disrupted by symptoms that are not responsive to medication. DBS can target the GPi, the ventral intermediate thalamic nucleus, the STN, and the pedunculopontine nucleus. DBS is not an alternative form of treatment, but a treatment that may be used in combination with pharmacotherapy to provide additional control over motor symptoms. DBS improves only certain symptoms (e.g., limb tremor, dyskinesia, limb bradykinesia, etc.); however many symptoms are unresponsive or may actually worsen following DBS procedures. For example, approximately 20% of patients receiving thalamic DBS experience dysarthria (Limousin & Martinez-Torres, 2008). Similarly, roughly 10% experience a deterioration in balance (Limousin & Martinez-Torres,

2008). Thus, these surgical procedures are options for only a small portion of the PD population. Moreover, they do not eliminate the need for additional treatment options that target the L-Dopa unresponsive symptoms of PD.

1.4.3 Rehabilitation Therapies

Because pharmaceutical and surgical interventions do not alleviate every symptom of PD at all stages of the disease, other treatments come in the form of rehabilitation from allied health disciplines (e.g., speech-language pathology for speech or swallowing concerns, physical therapy for mobility, and occupational therapy for functional mobility and cognition). These rehabilitative approaches use adjunct therapies to help people with PD manage the symptoms that interfere with their functioning, safety, and/or quality of life.

1.5 Gait Presentation in PD

Gait impairment is a significant symptom of PD. Healthy gait follows a rhythmic and symmetric pattern among all four limbs, but this rhythmicity and symmetry is altered in PD (Baltadjieva, Giladi, Gruendlinger, Peretz, & Hausdorff, 2006). Changes in the spatial and temporal coordination of limbs are observed and eventually interfere with the ability to ambulate in a timely, stable, and functional way (Balash et al., 2005; Bloem, Grimergen, Cramer, Willemsen, & Zwinderman, 2001). As a result, Parkinsonian gait impairments significantly impact quality of life and safety. Over 70% of people with Parkinson's experience at least one fall over the course of a year and approximately 75% of injuries acquired from a fall require healthcare services (Balash et al., 2005; Wielinski, Erickson-Davis, Wichmann, Walde-Douglas, & Parashos, 2005). People with PD report significant activity limitations due to gait dysfunction and fear of falling, even in early stages of the condition, which reportedly produces feelings of isolation and life dissatisfaction (Baltadjieva et al., 2006; Bloem et al., 2001; Marr, 1991; Schrag, Jahanshahi, & Quinn, 2000; Soundy, Stubbs, & Roskell, 2013).

The Parkinsonian gait is a slow, shuffling walking pattern (Bugalho, Alves, & Miguel, 2013) that is characterized by decreased stride length, slower stride time and, consequently, slower

stride velocity (Ebersbach, Moreau, Gandor, Defebvre, & Devos, 2013; Švehlík et al., 2009). Gait is less stable and more irregular than that of healthy adults, as indicated by an increased percentage of double-limb support time and increased stride-to-stride variability (Blin, Ferrandez, & Serratrice, 1990; Hausdorff, Cudkowicz, Firtion, Wei, & Goldberger, 1998). These gait changes are observed early in the disease and are consequently a prominent aspect of the condition that must be managed at varying levels of severity and for the entirety of the disease (Baltadjieva et al., 2006). These changes in speed and stability are closely tied to one's ability to complete activities of daily living independently and safely (Moore, Peretz, & Giladi, 2007). For this reason, physical and occupational therapy are often involved to recommend rehabilitative and remedial strategies to improve gait and safety. With disease progression, gait impairments increase in severity, with festinating and freezing of gait presenting marked interference for independent mobility (Ellis et al., 2011; Tan, McGinley, Danoudis, Iansek, & Morris, 2011).

Gait changes occur during healthy ageing, even in the absence of neurological pathology like PD. Older adults exhibit slower walking patterns with smaller strides, greater double-limb support time (DLST) and larger stride width than younger adults (Aboutorabi, Arazpour, Bahramizadeh, Hutchins, & Fadayevatan, 2016). However, the magnitude of these changes in healthy adults is not as severe as in PD (Hausdorff et al., 1998; Sofuwa et al., 2005). Age-related gait changes may be associated with a variety of factors that are not diagnosis specific. Examples of factors include decreased strength and lower force production (Perry, Carville, Smith, Rutherford, & Newham, 2007); musculoskeletal changes limiting range of motion; changes in executive or attention functioning (Amboni, Barone, & Hausdorff, 2013); and neural changes in white and grey matter (Callisaya et al., 2013). Age-related gait changes may also reflect compensatory strategies to increase stability and reduce the risk of falling or reduce energy expenditure (Aboutorabi et al., 2016). Knowledge of how therapeutic strategies impact gait throughout the aging process and in PD may provide insight into how these strategies work.

1.6 Internal Timing & Parkinson's

People with PD demonstrate impaired timing abilities, and some hypothesize that this may underlie gait changes in the condition (Nombela, Hughes, Owen, & Grahn, 2013; Skodda, Flasskamp, & Schlegel, 2010). While timing abilities in respect to movement are more readily noticeable in PD (i.e., difficulty regulating a consistent amplitude or speed of repetitive movement, as can be observed during finger or foot tapping tasks), there are also changes in timing abilities at a purely perceptual level (Cameron, Pickett, Earhart, & Grahn, 2016; J. A. Grahn & Brett, 2009; Pastor, Artieda, Jahanshahi, & Obeso, 1992; Smith, Harper, Gittings, & Abernethy, 2007). In other words, changes in timing abilities exist independently of movement.

1.6.1 Non-Music Timing Tasks

Timing abilities have been studied in the form of basic, non-motor timing tasks, such as estimating durations of time intervals and reproducing timing intervals by verbally indicating when an interval should end (Pastor et al., 1992; Smith et al., 2007). For example, people with PD are more variable in the accuracy of their timing estimation compared to healthy controls, and they tend to underestimate timing intervals (Pastor et al., 1992; Smith et al., 2007). Notably, these patterns of disrupted timing persist in PD when motor systems are recruited by reproducing time intervals through motor response (e.g., tapping tasks) (Honma, Kuroda, Futamura, Shiromaru, & Kawamura, 2016; Pastor et al., 1992). In other words, there are impairments in both reproduction and perception of timing information.

1.6.2 Music-Based Timing Tasks

Impaired timing perception has also been observed on rhythm-based tasks (Cameron et al., 2016; Grahn & Brett, 2007; Grahn & Brett, 2009). Rhythms (i.e., a sequence of tones separated by intervals of silence) offer an alternative means of investigating timing perception because we must correctly perceive durations of time between tones (inter-tone intervals) to accurately recognize or reproduce previously heard rhythms. Thus, timing abilities can be assessed by having listeners discriminate among rhythms or reproduce rhythms after hearing them.

Certain rhythmic structures (or temporal patterns) can cause listeners to perceive a regular pulse in a temporal sequence, known as the beat (Povel & Essens, 1985). This perception of a

beat is often experienced as a "stronger" or more salient tone in the rhythm which occurs at regular intervals. When we listen to music, the beat is often emphasized by musicians (e.g., by increasing loudness) (Ellis & Jones, 2009; Lenc, Keller, Varlet, & Nozaradan, 2018). However, this beat percept can be experienced even in rhythms comprised only of pure (sine) tones with no variability in acoustic properties such as pitch or amplitude (Ellis & Jones, 2009; Grahn & Brett, 2007; Grube & Griffiths, 2009; Kung, Chen, Zatorre, & Penhune, 2013; Povel & Okkerman, 1981). In other words, beat perception can arise solely from the temporal spacing of onsets of tones that are otherwise identical.

Therefore, the temporal structure of a rhythm is crucial to the experience a beat percept. Rhythms in music generally have a clear, periodic beat. However, it is possible to construct temporal sequences in which no beat can be perceived. Nonbeat rhythms follow no regular temporal structure and tone onsets are spaced irregularly in time. In these rhythms, it is impossible for listeners to perceive any kind of pulse, or beat, and therefore it is difficult for listeners to tap along to the rhythm in a regular way.

Rhythm provides a helpful paradigm to explore timing abilities. Typically healthy people are much more accurate in reproducing beat rhythms than nonbeat rhythms (Essens, 1986; Cameron et al., 2016; Grahn & Brett, 2009). This pattern is weaker among people with PD. Instead, people with PD perform only marginally better on beat than non-beat rhythms, thus suggesting that their timing perception does not benefit from the perception of a beat (Cameron et al., 2016; Grahn & Brett, 2009). This may reflect impaired processing of beat structure or impaired use of beat structure to benefit performance by PD patients, as suggested by Grahn & Brett (2009). Cameron and colleagues (2016) replicated this finding in PD patients in an on/off medication paradigm and found that discrimination accuracy between beat-based rhythms significantly improved on medication, when compared to testing off medication. In addition, they found that people presenting with more severe PD symptoms demonstrated lower accuracy (Cameron et al., 2016). Benoit and colleagues (2014) report a similar trend in a musically-cued gait training study. They report that PD participants are significantly less accurate than controls at the pre-test time point on a battery of both perceptual and motor timing tasks, including the beat alignment test. PD patients were also less accurate at detecting tempo changes during an adaptive tapping task where they had to

adjust their tapping rate to match tempo changes. Thus, PD patients demonstrate less accurate perceptual and motor performance than healthy controls on rhythm-based timing tasks.

1.6.3 Neurological Mechanisms of Timing in PD

The neural mechanisms underlying timing abilities are complex. For the purpose of this dissertation, it is important to understand that there is extensive overlap between the brain regions active during temporal processing and those affected in PD. Previous research has shown that, in particular, the BG and the supplementary motor areas (SMA) are crucial brain regions for processing beat-based timing information, yet activity in these regions is markedly lower in people with PD (Grahn & Brett, 2007; Grahn & Brett, 2009; Haslinger et al., 2001; Jahanshahi, Jenkins, Brown, & Marsden, 1995; Rascol et al., 1994). Although differences in these activation patterns explain the observed timing deficits in PD, it leaves uncertainty regarding how auditory cueing benefits gait in PD. Many theories have been proposed, but two particular theories have gained attention. One hypothesis suggests that auditory cueing may bypass or supplement the deficient internal volitional movement network comprised of the BG and SMA by activating a compensatory external cueing network comprised primarily of the cerebellum and premotor cortex (PMC) (Kotz, Schwartze, & Schmidt-Kassow, 2009). Another possibility is that musical cueing may offer additional benefits not entirely rooted in timing mechanisms, for example reward. This may then stimulate dopamine release in the basal ganglia in an alternative way, allowing more efficient release of the non-depleted dopamine (Nombela et al., 2013; Thaut & Abiru, 2010). However, the neural mechanisms are not entirely understood and require a better understanding of the behavioural patterns associated with auditory cueing to fully understand the underlying neural substrates.

1.7 Auditory Cueing/Rhythmic Auditory Stimulation (RAS)

Rhythmic auditory stimulation (RAS) is a strategy for gait rehabilitation that capitalizes on the innate tendency we have to move with a beat in a synchronized way (also known as sensorimotor synchronization or motor entrainment). This technique uses an auditory stimulus with regular, rhythmic properties, such as a metronome or beat-salient music where the beat is easily identified, to cue timing regularity during walking. RAS can be used as an adjunct therapy to medication, as it is a low risk intervention with minimal cost and minimal negative

side effects. The general principle behind auditory cueing is that coordinating movements to be in time with a regular auditory stimulus can foster motor entrainment that will translate into a more appropriately timed gait pattern that is faster and less variable (Ghai et al., 2018). This technique has been applied broadly in gait rehabilitation, among many conditions other than PD, such as multiple sclerosis, spinal cord injury, cerebral palsy, and stroke (Cha, Kim, & Chung, 2014; Shahraki, Sohrabi, Taheri Torbati, Nikkhah, & NaeimiKia, 2017; Thaut et al., 2007). However, it has gained the most interest in PD literature as it is widely accepted that RAS can enhance gait in PD (Ghai et al., 2018; Lim et al., 2005; Spaulding et al., 2013). RAS is incorporated into national guidelines as a rehabilitative gait strategy for both physical and occupational therapists working with PD (Aragon & Kings, 2018; Keus, Bloem, Hendriks, Bredero-Cohen, & Munneke, 2007; Sturkenboom et al., 2008)

RAS studies have shown improvements in gait velocity, cadence, stride length, double-limb support time, and gait variability (coefficient of variation for stride time and stride length) with various approaches to the intervention (Brown, de Bruin, Doan, Suchowersky, & Hu, 2010; de Bruin et al., 2010; McIntosh, Brown, Rice, & Thaut, 1997; Nieuwboer et al., 2007; Rochester et al., 2005; Thaut et al., 1996). Multiple meta-analyses and systematic reviews have supported this following review of the literature on RAS and PD (Ghai et al., 2018; Lim et al., 2005; Rocha, Porfírio, Ferraz, & Trevisani, 2014; Spaulding et al., 2013). However, these reviews have also highlighted that the exact effects observed (i.e., which spatiotemporal gait parameters) and the degree to which they change with RAS are not consistent. This may be due, in part, to how variable the Parkinson's condition can be and that many PD samples are small. However, the strategies for implementing RAS vary significantly from study to study as well. There are many aspects of RAS that vary across studies, not all of which are within the scope of this dissertation. Common factors that vary among studies are the tempo of auditory cues, the type of stimulus used, the intensity of training, and the overarching gait task. This methodological variability can make it difficult for both researchers and clinicians to interpret the overall effects of auditory cueing on gait and determine when/how to use it appropriately. There is not a clear consensus in the literature of all the factors that should be accounted for to produce controlled and optimal gait outcomes. However, there is increasing recognition that RAS may require some level of individualization. Recently, it has been suggested that different cue tempi yield different effects (e.g., cues slower than preferred pace

minimally impact velocity but increase stride length; cues faster than preferred pace increase velocity but not stride length) (Ghai et al., 2018; Willems et al., 2006). With this knowledge, it is suggested that tempi perhaps have to be selected based on which gait changes are most prominent for an individual (Morris, Martin, & Schenkman, 2010; Willems et al., 2006). Similarly, some literature suggests that individual rhythmic ability or musical perception may influence RAS outcomes and be a powerful avenue for RAS individualization (Dalla Bella et al., 2017; Dalla Bella, Dotov, Bardy, & Cock Valérie, 2018; Leow, Parrott, & Grahn, 2014; Leow, Rinchon, & Grahn, 2015). In this dissertation, the importance of variability in stimuli and instruction type in relation to individual beat perception ability will be explored. These factors will be discussed in more detail below.

1.7.1 Music-based RAS

Music can be used as a rhythmic auditory cue (or music-based gait training), either in place of/in combination with a metronome. Music-based RAS, at face value, may be more enjoyable to users which may contribute to therapy adherence (de Bruin et al., 2015). However, music may afford benefits beyond the enjoyable aspects of music-listening by increasing motor engagement and neural activation.

1.7.1.1 Music and Reward

People enjoy listening to and engaging with music. Thus, it is not surprising that music listening activates reward centres in the brain (e.g., limbic system). Neuroimaging studies have shown that both the dorsal and ventral striatum are highly active when listening to pleasurable music, which are respectively associated with movement and pleasure (Zatorre, 2015). Reward and enjoyment may mediate movement timing and speed, both in healthy groups and the PD population (Mazzoni, Hristova, & Krakauer, 2007; Niv, Joel, & Dayan, 2006); thus, activation of reward and enjoyment networks in the brain may directly impact both spatial and temporal gait parameters during RAS. However, this has not been supported in the RAS literature. Roberts (2017) investigated the role of music enjoyment on gait outcomes in healthy younger and older adults, and found no improvement in gait speed or stride length for highly enjoyable versus un-enjoyable music. The author hypothesized that walking to enjoyable music could enhance motor performance (i.e., increase gait speed, stride

length) by increasing movement speed or vigor. However, this was not the case and suggests that the enjoyable properties of music, though they may increase therapeutic adherence, do not influence gait changes in response to music.

1.7.1.2 Music and Motor System Activation

Music also activates motor regions, such as the PMC, the SMA, the cerebellum, and the BG. This is true regardless of enjoyment and even when listeners are not moving (Chen, Penhune, & Zatorre, 2008; Grahn & Brett, 2009). Beat-based timing, which is involved in music listening, increases connectivity between auditory and motor systems (Kung et al., 2013) and higher beat salience has been associated with greater motor-evoked potentials during transcranial magnetic stimulation (TMS) than are observed for music with low beat salience (Cameron, Stewart, Pearce, Grube, & Muggleton, 2012).

Importantly, motor system activation may be strongly mediated by how much the music produces a desire to move for the listener. In the music cognition literature, this concept of wanting to move to the beat in music (e.g., tapping foot, swaying, bobbing head) is called groove (Madison, 2006). Music perceived to be higher in groove evokes strong desires to move, or stronger auditory-motor coupling, and music lower in groove is associated with less (or no) desire to move, or weaker auditory-motor coupling. The neural literature related specifically to groove-perception in music is sparse; however, one TMS study has shown modulation of the motor cortex for high groove but not low groove music (Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller, 2013). In this study, participants were instructed not to move while receiving single-pulse TMS over the primary motor cortex for high groove music, low groove music, and white noise. Motor-evoked potentials (MEPs) were significantly altered for high groove music (in comparison to low groove and white noise, for which MEPs did not differ). Notably, the modulation trends observed were different for musicians (larger MEPs) versus non-musicians (lower MEPs), suggesting that musical training may influence motor system activation to high groove music.

In spite of sparse neurological research on groove perception, behavioural research supports that perception of groove in music impacts frequency and intensity of movement. Janata and colleagues (2012) observed significantly more spontaneous and synchronized movement at

the head, trunk, and extremities to high groove music (versus low groove) during music listening when participants were instructed to not move with the music. In other words, participants demonstrated more auditory-motor synchronization to high versus low groove music. Moreover, participants reported that tapping was easier to high groove than groove music (Janata et al., 2012). This suggests that the sensorimotor coupling occurs with less effort for high groove music instead of low groove music.

Similar findings have been observed in gait studies using music. Using a RAS paradigm, Leow and colleagues (2015) instructed participants to walk with the beat of high and low groove music ranging in familiarity. The authors found that high groove music consistently produced faster stride velocity and larger stride length when compared to low groove music. Another recent study demonstrated that participants show a similar trend of faster and larger strides to high versus low groove regardless of beat perception ability, stimulus familiarity, or intent to synchronize or not (Ready, McGarry, Rinchon, Holmes, & Grahn, 2019). Additionally, these studies both found that synchronization ability (or ability to match the tempo of music) is more accurate for high versus low groove music. This has significant implications for RAS as an intervention which is highly dependent on synchronization ability and will be explored in this dissertation.

1.7.2 Beat Perception/Production Ability and RAS

As previously reviewed, the temporal structure of a rhythm significantly impacts a person's ability to both hear and tap a beat out while listening to a rhythm (in addition to their ability to correctly recognize or reproduce the rhythm as a whole). However, beat perception accuracy is not equal across all people (Dalla Bella, Sowi, & ski, 2015; Launay, Grube, & Stewart, 2014; Leow et al., 2014; Phillips-Silver et al., 2011) and can be influenced by many factors including musical training (Grahn & Rowe, 2009), age (Repp, 2013), cultural familiarity (Cameron, Bentley, & Grahn, 2015), and auditory short-term memory (Grahn & Schuit, 2012). Nevertheless, only a small portion of RAS studies account for these differences in individual rhythmic ability.

There are neural differences observed between good and poor beat perceivers. Using fMRI, Grahn and McAuley (2009) identified neural differences between good beat perceivers

(people who can accurately identify the beat in music) and poor beat perceivers (those who cannot as accurately identify a beat) during a rhythm discrimination task (2009). The authors discovered differences in the SMA (greater activity among good vs. poor beat perceivers) and the PMC (greater left PMC activity among good and greater right PMC activity among poor). These differences occur largely in brain regions known to be active during beat-based rhythm processing and motor planning/movement.

1.7.2.1 Sensorimotor Synchronization and Beat Ability

Auditory-motor synchronization is influenced by beat perception accuracy. Benoit et al. (2014) found significant differences for synchronization-continuation task for PD vs. healthy controls. Improved performance among PD participants following training suggests this may not be a result of general motor timing deficits, but rather the perceptual timing deficits present in PD (Benoit, 2014). This is supported in the RAS literature both in healthy young adults and in people with PD. In a music-based auditory cueing study, Leow et al. (2014) found that healthy young adults with poor beat perception ability were significantly less accurate at synchronizing foot steps to a musical beat when instructed to than participants who demonstrated accurate beat perception ability. In addition, variability of synchronization was greater for poor beat perceivers than good beat perceivers. This suggests that they are both less accurate in synchronizing to the beat while walking but also less consistent in their synchronization while walking. Importantly, these effects interacted with the amount of groove perceived in music. This suggests that perceived groove may mediate the effects of beat perception in synchronization ability. Similar trends have been observed in the Parkinson's population. Dalla Bella et al. (2017) PD participants with the most impaired rhythmic ability demonstrated different responses to auditory cueing than those with less impaired rhythmic ability. In this study, participants were classified as responders if they demonstrated clinically meaningful gait improvements (Dalla Bella et al., 2017). Non-responders were classified as such if they demonstrated no change/clinically meaningful gait deterioration.

1.7.2.2 Stimulus Familiarity and Beat Ability

Importantly, familiarity with a stimulus may facilitate sensorimotor synchronization or reduce the cognitive demands associated with synchronization through familiarity with the beat structure. Leow et al. (2015) demonstrated in a RAS study that gait synchronization is significantly more accurate for highly familiar versus unfamiliar music. The authors suggest that this may reflect greater familiarity with the beat structure and a reduced need to focus on prediction of beat onsets. They hypothesize that this reduces cognitive demand during highly familiar conditions and is related to the increase in gait speed observed in these trials, as slower gait speeds are often reported during dual-tasking in healthy young adult populations (Al-Yahya et al., 2011; Leow et al., 2015). These findings were not replicated by Ready et al. (2019) in a similar RAS study among young adults walking to high and low familiarity stimuli. The authors did not find significant differences for any spatiotemporal gait parameters (including stride time and velocity, as above) for high and low familiarity. Therefore, the impact of stimulus familiarity on gait outcomes in RAS is not entirely clear. Importantly, the findings from Leow et al. (2014) are consistent with literature exploring the impact of culturally familiar rhythmic structure on beat tapping. Cameron et al. (2015) found that participants tapped the beat more accurately to culturally familiar versus unfamiliar rhythms (i.e., Western participants were more accurate with Western rhythms than East-African rhythms, and vice versa).

1.7.3 Synchronized RAS – A dual task

RAS often operates on the premise that deliberately synchronizing with an auditory stimulus contributes to entrainment and the effects of RAS on gait. For this reason, the majority of studies on RAS incorporate synchronization instructions as part of the protocol. Despite this being an integral part of the intervention, few studies have actually explored the role of instructions to synchronize on RAS outcomes.

Synchronization is less frequent and less accurate when participants are not instructed to synchronize (Leow, Waclawik, & Grahn, 2018; Mendonça, Oliveira, Fontes, & Santos, 2014). However, Leow et al. (2018) found that this effect was influenced by how close the cued tempo was to a person's natural walking rate (participants, particularly uninstructed

participants, demonstrate poorer synchronization as the tempo deviates further from their preferred gait tempo). This may explain some contrasting effects observed by Ready et al. (2019) in a RAS study where cues delivered at baseline walking rate elicited gait tempo-matching to both metronome and high groove music cues, regardless of instructions to synchronize. Synchronization did not occur for low groove cues.

Beneficial effects of RAS can still occur in the absence of synchronization to cues (Benoit et al., 2014; de Bruin et al., 2015; Wittwer, Webster, & Hill, 2013). Several studies support that spatiotemporal gait improvements can occur even when walkers instructed to synchronize do not demonstrate accurate synchronization (Wittwer, Webster, & Hill, 2013) and when participants are walking with no intent to synchronize (Benoit et al., 2014; de Bruin et al., 2015). In fact, some findings suggest that intent to synchronize may negatively impact gait patterns by increasing gait variability and slowing/shortening strides (Leow et al., 2018). Studies exploring the impact of rhythmic ability on RAS outcomes suggest that poor performance during synchronized RAS (i.e., inaccurate synchronization or detriment in spatiotemporal gait patterns) may be related to poor rhythmic abilities (Dalla Bella et al., 2018; Leow et al., 2014; Ready et al., 2019). People with poorer rhythmic ability demonstrate slower, more variable gait patterns that closely resemble dual-tasking gait patterns. Leow et al. (2014) found shorter, slower, and more variable strides among poor beat perceivers versus good beat perceivers during synchronized walking. Similarly, Dalla Bella et al. (2017) concluded that rhythmic skills in a PD group were predictive of gait velocity changes during RAS. Ready et al. (2019) did not corroborate the findings that poor beat perceivers slow and shorten strides during synchronized walking. However, the authors did find that poor beat perceivers walked with more narrow strides during uninstructed (free) walking than when they were instructed to synchronize, potentially indicating that uninstructed walking facilitated a more stable gait pattern by reducing cognitive demand. Importantly, many studies conclude that synchronizing does not compromise gait (in healthy adults and PD groups); thus the impact of synchronization demands on gait during RAS remain unclear.

High cognitive load while walking can cause slowing and shortening of strides, higher overall gait variability, and the need for a wider stance (Heinzel et al., 2016; Kelly, Eusterbrock, Shumway-Cook, 2012; O'Shea, Morris, & Iansek, 2002; Stegemöller et al., 2014; Yogev et

al., 2005). This gait deterioration is frequently referred to as “dual-task interference” and reflects a more cautious and less-controlled gait pattern. People with PD are more susceptible to dual-task interference on gait than the average, healthy older adult (O'Shea, Morris, & Iansek, 2002; Yogev et al., 2005). This sensitivity to dual-task interference puts people with PD at a high fall risk when completing secondary tasks while walking (Heinzel et al., 2016). For this reason it is crucial to optimize RAS in a way that limits dual-task demands and fosters the safest and most functional gait pattern.

1.8 Thesis Overview

This introduction outlines how sensorimotor synchronization can be influenced by a number of factors that may impact RAS outcomes. Spontaneous synchronization and ease of synchronization can be enhanced by higher levels of perceived groove. Additionally, greater beat perception ability enhances synchronization accuracy, and beat prediction can be improved through familiarity with a stimulus. While several studies have explored synchronized RAS and aspects of these factors, no studies to date have accounted for the impact of these three factors together on gait responses to RAS with and without instructions to synchronize. This dissertation aims to explore the relationship among levels of perceived groove, beat perception ability, stimulus familiarity, and instructions to synchronize on gait outcomes during music-based RAS. Gait patterns, sensitivity to dual-task interference, and synchronization abilities can vary across the lifespan; therefore, this thesis set out to explore these factors among young adults (Chapter 3), older adults (Chapter 4), and people with PD (Chapter 5). The aim of this dissertation is to increase knowledge of the relationship between music and movement and to further understand what, if any, of the above factors must be controlled to increase music-based RAS efficacy.

References

Aboutorabi, A., Arazpour, M., Bahramizadeh, M., Hutchins, S. W., & Fadayevatan, R. (2016). The effect of aging on gait parameters in able-bodied older subjects: a literature review. *Aging Clinical and Experimental Research, 28*(3), 393-405. doi:10.1007/s40520-015-0420-6

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews, 35*(3), 715-728. doi:10.1016/j.neubiorev.2010.08.008

Amboni, M., Barone, P., & Hausdorff, J. M. (2013). Cognitive contributions to gait and falls: evidence and implications. *Movement disorders : official journal of the Movement Disorder Society, 28*(11), 1520-1533. doi:10.1002/mds.25674

Baltadjieva, R., Giladi, N., Gruendlinger, L., Peretz, C., & Hausdorff, J. M. (2006). Marked alterations in the gait timing and rhythmicity of patients with de novo parkinson's disease. *European Journal of Neuroscience, 24*(6), 1815-1820. doi:10.1111/j.1460-9568.2006.05033.x

Balash, Y., Peretz, C., Leibovich, G., Herman, T., Hausdorff, J. M., & Giladi, N. (2005). Falls in outpatients with Parkinson's disease. *Journal of Neurology, 252*(11), 1310-1315. doi:10.1007/s00415-005-0855-3

Benoit, C.-E., Dalla Bella, S., Farrugia, N., Obrig, H., Mainka, S., & Kotz, S. A. (2014). Musically Cued Gait-Training Improves Both Perceptual and Motor Timing in Parkinson's Disease. *Frontiers in Human Neuroscience, 8*(494). doi:10.3389/fnhum.2014.00494

Blin, O., Ferrandez, A. M., & Serratrice, G. (1990). Quantitative analysis of gait in Parkinson patients: increased variability of stride length. *J Neurol Sci, 98*(1), 91-97.

Bloem, B. R., Grimbergen, Y. A. M., Cramer, M., Willemsen, M., & Zwinderman, A. H. (2001). Prospective assessment of falls in parkinson's disease. *Journal of Neurology, 248*(11), 950-958. doi:10.1007/s004150170047

Bugalho, P., Alves, L., & Miguel, R. (2013). Gait dysfunction in Parkinson's disease and normal pressure hydrocephalus: a comparative study. *Journal of Neural Transmission, 120*(8), 1201-1207. doi:10.1007/s00702-013-0975-3

Callisaya, M. L., Beare, R., Phan, T. G., Blizzard, L., Thrift, A. G., Chen, J., & Srikanth, V. K. (2013). Brain structural change and gait decline: a longitudinal population-based study. *J Am Geriatr Soc, 61*(7), 1074-1079. doi:10.1111/jgs.12331

Cameron, D. J., Bentley, J., & Grahn, J. A. (2015). Cross-cultural influences on rhythm processing: reproduction, discrimination, and beat tapping. *Frontiers in psychology, 6*(366). doi:10.3389/fpsyg.2015.00366

Cameron, D. J., Stewart, L., Pearce, M. T., Grube, M., & Muggleton, N. G. (2012). Modulation of Motor Excitability by Metricality of Tone Sequences. *Psychomusicology: Music, Mind, and Brain, 22*(2), 122-128. doi:10.1037/a0031229

Canadian Institute for Health Information. (2007). *The Burden of Neurological Diseases, Disorders and Injuries in Canada* Ottawa: CIHI.

Casarotto, S., Turco, F., Comanducci, A., Perretti, A., Marotta, G., Pezzoli, G., . . . Isaias, I. U. (2019). Excitability of the supplementary motor area in parkinson's disease depends on subcortical damage. *Brain Stimulation, 12*(1), 152-160. doi:10.1016/j.brs.2018.10.011

Cha, Y., Kim, Y., & Chung, Y. (2014). Immediate effects of rhythmic auditory stimulation with tempo changes on gait in stroke patients. *Journal of Physical Therapy Science, 26*(4), 479-482. doi:10.1589/jpts.26.479

Chen, J. L., Penhune, V. B., & Zatorre, R. J. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cereb Cortex, 18*(12), 2844-2854. doi:10.1093/cercor/bhn042

Dalla Bella, S., Benoit, C. E., Farrugia, N., Keller, P. E., Obrig, H., Mainka, S., & Kotz, S. A. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Sci Rep, 7*, 42005. doi:10.1038/srep42005

Dalla Bella S., Dotov, D., Bardy, B., & Cock Valérie, C. (2018). Individualization of music-based rhythmic auditory cueing in Parkinson's disease. *Annals of the New York Academy of Sciences, 0*(0). doi:10.1111/nyas.13859

Dalla Bella, S., Sowi, & ski, J. (2015). Uncovering Beat Deafness: Detecting Rhythm Disorders with Synchronized Finger Tapping and Perceptual Timing Tasks. *Journal of Visualized Experiments*(97), e51761. doi:doi:10.3791/51761

de Bruin, N., Kempster, C., Doucette, A., Doan, J. B., Hu, B., & Brown, L. A. (2015). The effects of music salience on the gait performance of young adults. *Journal of Music Therapy, 52*(3), 394-419. doi:10.1093/jmt/thv009

de Lau, L. M., & Breteler, M. M. (2006). Epidemiology of Parkinson's disease. *Lancet Neurology, 5*(6), 525-535. doi:10.1016/S1474-4422(06)70471-9

DeLong, M. R. (1990). Primate models of movement disorders of basal ganglia origin. *Trends in Neurosciences, 13*(7), 281-285.

Ebersbach, G., Moreau, C., Gandor, F., Defebvre, L., & Devos, D. (2013). Clinical syndromes: Parkinsonian gait. *Movement Disorders, 28*(11), 1552-1559. doi:10.1002/mds.25675

Ellis, R. J., & Jones, M. R. (2009). The role of accent salience and joint accent structure in meter perception. *Journal of Experimental Psychology: Human Perception and Performance, 35*(1), 264-280.

Essens, P.J. (1986). Hierarchical organization of temporal patterns. *Perception & Psychophysics, 40*(2), 69-73. https://doi.org/10.3758/BF03208185

Fahn, S. (1999). Parkinson disease, the effect of levodopa, and the elldopa trial. *Archives of Neurology, 56*(5), 529-535. doi:10.1001/archneur.56.5.529

Fahn, S., Oakes, D., Shoulson, I., Kieburtz, K., Rudolph, A., Lang, A., . . . Parkinson Study, G. (2004). Levodopa and the Progression of Parkinson's Disease. *The New England Journal of Medicine, 351*(24), 2498-2508.

Farrer, M. J. (2006). Genetics of Parkinson disease: paradigm shifts and future prospects. *Nature Reviews. Genetics, 7*(4), 306-318. doi:http://dx.doi.org/10.1038/nrg1831

Grube, M., & Griffiths, T. D. (2009). Metricality-enhanced temporal encoding and the subjective perception of rhythmic sequences. Cortex, 45(1), 72-79. doi:10.1016/j.cortex.2008.01.006

Ghai, S., Ghai, I., Schmitz, G., & Effenberg, A. O. (2018). Effect of rhythmic auditory cueing on parkinsonian gait: A systematic review and meta-analysis. *Sci Rep, 8*(1), 506. doi:10.1038/s41598-017-16232-5

Grahn, J. A., & Brett, M. (2007). Rhythm and beat perception in motor areas of the brain. Journal of *Cognitive Neuroscience, 19*(5), 893-906. doi:10.1162/jocn.2007.19.5.893

Grahn, J. A., & Brett, M. (2009). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex, 45*(1), 54-61. doi:10.1016/j.cortex.2008.01.005

Grahn, J. A., & Rowe, J. B. (2009). Feeling the beat: premotor and striatal interactions in musicians and nonmusicians during beat perception. *J Neurosci, 29*(23), 7540-7548. doi:10.1523/jneurosci.2018-08.2009

Grahn, J. A., & Schuit, D. (2012). Individual Differences in Rhythmic Ability: Behavioral and Neuroimaging Investigations. *Psychomusicology, 22*(2), 105-121. doi:10.1016/ S1364-6613(00)01538-2

Gupta, S. M. D. (2002). Anatomy and physiology of the Basal Ganglia. *Psychiatric Annals, 32*(4), 230-232.

Haslinger, B., Erhard, P., Kämpfe, N., Boecker, H., Rummeny, E., Schwaiger, M., . . . Ceballos-Baumann, A. O. (2001). Event-related functional magnetic resonance imaging in parkinson's disease before and after levodopa. *Brain, 124*(3), 558-570. doi:10.1093/brain/124.3.558

Hausdorff, J. M., Cudkowicz, M. E., Firtion, R., Wei, J. Y., & Goldberger, A. L. (1998). Gait variability and basal ganglia disorders: stride-to-stride variations of gait cycle timing in Parkinson's disease and Huntington's disease. *Mov Disord, 13*. doi:10.1002/mds.870130310

Hausdorff, J. M., Cudkowicz, M. E., Firtion, R., Wei, J. Y., & Goldberger, A. L. (1998). Gait variability and basal ganglia disorders: Stride-to-stride variations of gait cycle timing in parkinson's disease and Huntington's disease. *Movement Disorders, 13*(3), 428-437. doi:10.1002/mds.870130310

Health Canada, & Parkinson Society Canada. (2003). *Parkinson's Disease: Social and Economic Impact*. Toronto: PSC.

Heinzel, S., Maechtel, M., Hasmann, S. E., Hobert, M. A., Heger, T., Berg, D., & Maetzler, W. (2016). Motor dual-tasking deficits predict falls in parkinson's disease: A prospective study. Parkinsonism and Related Disorders, 26, 73-77. doi:10.1016/j.parkreldis.2016.03.007

Honma, M., Kuroda, T., Futamura, A., Shiromaru, A., & Kawamura, M. (2016). Dysfunctional counting of mental time in Parkinson's disease. *Sci Rep, 6,* 25421. doi:10.1038/srep25421

Hung, A., & Schwarzschild, M. (2014). Treatment of Parkinson's Disease: What's in the Non-dopaminergic Pipeline? *Neurotherapeutics, 11*(1), 34-46. doi:10.1007/s13311-013-0239-9

Inzelberg, R., Schechtman, E., & Paleacu, D. (2002). Onset age of Parkinson disease. *American Journal of Medical Genetics, 111*(4), 459-460. doi:10.1002/ajmg.10586

Jahanshahi, M., Jahanshahi, M., Jenkins, I. H., Jenkins, I. H., Brown, R. G., Brown, R. G., . . . Brooks, D. J. (1995). Self-initiated versus externally triggered movements I. an investigation using measurement of regional cerebral blood flow with PET and movement-related potentials in normal and parkinson's disease subjects. *Brain, 118*(4), 913-933. doi:10.1093/brain/118.4.913

Janata, P., Tomic, S. T., & Haberman, J. M. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General, 141*(1), 54-75. doi:http://dx.doi.org/10.1037/a0024208

Jankovic, J. (2008). Parkinson's disease: clinical features and diagnosis. *Journal of Neurology, Neurosurgery & Psychiatry, 79*(4), 368-376. doi:10.1136/jnnp.2007.131045

Kelly, V. E., Eusterbrock, A. J., & Shumway-Cook, A. (2012). A review of dual-task walking deficits in people with Parkinson's disease: motor and cognitive contributions, mechanisms, and clinical implications. Parkinson's disease, 2012, 918719. doi:10.1155/2012/918719

Kim, S. D., Allen, N. E., Canning, C. G., & Fung, V. S. C. (2013). Postural Instability in Patients with Parkinson's Disease: Epidemiology, Pathophysiology and Management. *CNS Drugs, 27*(2), 97-112. doi:10.1007/s40263-012-0012-3

Kung, S. J., Chen, J. L., Zatorre, R. J., & Penhune, V. B. (2013). Interacting cortical and basal ganglia networks underlying finding and tapping to the musical beat. *J Cogn Neurosci, 25*(3), 401-420. doi:10.1162/jocn_a_00325

Launay, J., Grube, M., & Stewart, L. (2014). Dysrhythmia: a specific congenital rhythm perception deficit. *Front Psychol, 5*, 18. doi:10.3389/fpsyg.2014.00018

Lenc, T., Keller, P. E., Varlet, M., & Nozaradan, S. (2018). Neural tracking of the musical beat is enhanced by low-frequency sounds. *Proceedings of the National Academy of Sciences of the United States of America, 115*(32), 8221-8226. doi:10.1073/pnas.1801421115

Leow, L.-A., Parrott, T., & Grahn, J. A. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Leow, L.-A., Rinchon, C., & Grahn, J. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *Annals of the New York Academy of Sciences, 1337*(1), 53-61. doi:10.1111/nyas.12658

Leow, L.-A., Waclawik, K., & Grahn, J. A. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research, 236*(1), 99-115. doi:10.1007/s00221-017-5110-5

Lim, I., van Wegen, E., de Goede, C., Deutekom, M., Nieuwboer, A., Willems, A., . . . Kwakkel, G. (2005). Effects of external rhythmical cueing on gait in patients with Parkinson's disease: a systematic review. *Clinical Rehabilitation, 19*(7), 695-713. doi:10.1191/0269215505cr906oa

Limousin, P., & Martinez-Torres, I. (2008). Deep brain stimulation for Parkinson's disease. *Neurotherapeutics, 5*(2), 309-319. doi:10.1016/j.nurt.2008.01.006

Macphee, G. J. A., & Stewart, D. A. (2012). Parkinson's disease – pathology, aetiology and diagnosis. *Reviews in Clinical Gerontology, 22*(3), 165-178. doi:10.1017/S095925981200007X

Mazzoni, P., Hristova, A., & Krakauer, J. W. (2007). Why Don't We Move Faster? Parkinson's Disease, Movement Vigor, and Implicit Motivation. *The Journal of Neuroscience, 27*(27), 7105. doi:10.1523/JNEUROSCI.0264-07.2007

McAuley, J. H., Daly, P. M., & Curtis, C. R. (2009). A preliminary investigation of a novel design of visual cue glasses that aid gait in Parkinson's disease. *Clinical Rehabilitation, 23*(8), 687-695. doi:10.1177/0269215509104170

Mendonça, C., Oliveira, M., Fontes, L., & Santos, J. (2014). The effect of instruction to synchronize over step frequency while walking with auditory cues on a treadmill. *Hum Mov Sci, 33*, 33-42. doi:10.1016/j.humov.2013.11.006

Moore, O., Peretz, C., & Giladi, N. (2007). Freezing of gait affects quality of life of peoples with Parkinson's disease beyond its relationships with mobility and gait. *Movement Disorders, 22*(15), 2192-2195. doi:10.1002/mds.21659

Morris, M. E., Martin, C. L., & Schenkman, M. L. (2010). Striding out with parkinson disease: Evidence-based physical therapy for gait disorders. *Physical Therapy, 90*(2), 280-288. doi:10.2522/ptj.20090091

Niv, Y., Joel, D., & Dayan, P. (2006). A normative perspective on motivation. *Trends in Cognitive Sciences, 10*(8), 375-381. doi:10.1016/j.tics.2006.06.010

O'Shea, S., Morris, M. E., & Iansek, R. (2002). Dual task interference during gait in people with Parkinson disease: Effects of motor versus cognitive secondary tasks. *Physical Therapy, 82*(9), 888-897.

Pastor, M. A., Artieda, J., Jahanshahi, M., & Obeso, J. A. (1992). Time estimation and reproduction is abnormal in Parkinson's disease. *Brain, 115 Pt 1*, 211-225.

Patel, N., Jankovic, J., & Hallett, M. (2014). Sensory aspects of movement disorders. *Lancet Neurology, 13*(1), 100-112. doi:10.1016/S1474-4422(13)70213-8

Perry, M. C., Carville, S. F., Smith, I. C. H., Rutherford, O. M., & Newham, D. J. (2007). Strength, power output and symmetry of leg muscles: effect of age and history of falling. *European Journal of Applied Physiology, 100*(5), 553-561. doi:10.1007/s00421-006-0247-0

Phillips-Silver, J., Toiviainen, P., Gosselin, N., Piché, O., Nozaradan, S., Palmer, C., & Peretz, I. (2011). Born to dance but beat deaf: A new form of congenital amusia. *Neuropsychologia, 49*(5), 961-969. doi:10.1016/j.neuropsychologia.2011.02.002

Povel, D.J. & Okkerman, H. (1981). Accents in equitone sequences. *Perception & Psychophysics, 30*(565). https://doi.org/10.3758/BF03202011

Rascol, O., Sabatini, U., Chollet, F., Fabre, N., Senard, J. M., Montastruc, J. L., . . . Rascol, A. (1994). Normal activation of the supplementary motor area in patients with parkinson's disease undergoing long-term treatment with levodopa. *Journal of Neurology Neurosurgery and Psychiatry, 57*(5), 567-571. doi:10.1136/jnnp.57.5.567

Ready, E. A., McGarry, L. M., Rinchon, C., Holmes, J. D., & Grahn, J. A. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait & Posture, 68*, 555-561. doi:https://doi.org/10.1016/j.gaitpost.2018.12.038

Roberts, B. S. (2017). *Comparing the influence of music enjoyment and beat perception ability on spatiotemporal gait parameters among healthy young and older adults.* (Master of Science), University of Western Ontario, Electronic Thesis and Dissertation Repository. Retrieved from https://ir.lib.uwo.ca/etd/4893 (4893)

Rocha, P. A., Porfírio, G. M., Ferraz, H. B., & Trevisani, V. F. M. (2014). Effects of external cues on gait parameters of Parkinson's disease patients: A systematic review. *Clinical Neurology and Neurosurgery, 124*, 127-134. doi:10.1016/j.clineuro.2014.06.026

Ruiz, P. J. G., Catalán, M. J., & Carril, J. M. F. (2011). Initial Motor Symptoms of Parkinson Disease. *The Neurologist, 17*, S18-S20. doi:10.1097/NRL.0b013e31823966b4

Schapira, A. H. V. (2009). Neurobiology and treatment of Parkinson's disease. *Trends in Pharmacological Sciences, 30*(1), 41-47. doi:10.1016/j.tips.2008.10.005

Sethi, K. (2008). Levodopa unresponsive symptoms in Parkinson disease. *Movement Disorders, 23*(S3), S521-S533. doi:10.1002/mds.22049

Shahraki, M., Sohrabi, M., Taheri Torbati, H. R., Nikkhah, K., & NaeimiKia, M. (2017). Effect of rhythmic auditory stimulation on gait kinematic parameters of patients with multiple sclerosis. *Journal of Medicine and Life, 10*(1), 33-37.

Shulman, J. M., De Jager, P. L., & Feany, M. B. (2011). Parkinson's Disease: Genetics and Pathogenesis. *Annual Review of Pathology: Mechanisms of Disease, 6*, 193-222. doi:10.1146/annurev-pathol-011110-130242

Smith, J. G., Harper, D. N., Gittings, D., & Abernethy, D. (2007). The effect of Parkinson's disease on time estimation as a function of stimulus duration range and modality. *Brain Cogn, 64*(2), 130-143. doi:10.1016/j.bandc.2007.01.005

Sofuwa, O., Nieuwboer, A., Desloovere, K., Willems, A. M., Chavret, F., & Jonkers, I. (2005). Quantitative Gait Analysis in Parkinson's Disease: Comparison With a Healthy Control Group. *Archives of Physical Medicine and Rehabilitation, 86*(5), 1007-1013. doi:10.1016/j.apmr.2004.08.012

Spaulding, S. J., Barber, B., Colby, M., Cormack, B., Mick, T., & Jenkins, M. E. (2013). Cueing and Gait Improvement Among People With Parkinson's Disease: A Meta-Analysis. *Archives of Physical Medicine and Rehabilitation, 94*(3), 562-570. doi:10.1016/j.apmr.2012.10.026

Stegemöller, E. L., Wilson, J. P., Hazamy, A., Shelley, M. C., Okun, M. S., Altmann, L. J., & Hass, C. J. (2014). Associations between cognitive and gait performance during single- and dual-task walking in people with Parkinson disease. *Physical therapy, 94*(6), 757–766. doi:10.2522/ptj.20130251

Stupacher, J., Hove, M. J., Novembre, G., Schütz-Bosbach, S., & Keller, P. E. (2013). Musical groove modulates motor cortex excitability: A TMS investigation. *Brain and Cognition, 82*(2), 127-136. doi:https://doi.org/10.1016/j.bandc.2013.03.003

Švehlík, M., Zwick, E. B., Steinwender, G., Linhart, W. E., Schwingenschuh, P., Katschnig, P., . . . Enzinger, C. (2009). Gait Analysis in Patients With Parkinson's Disease Off Dopaminergic Therapy. *Archives of Physical Medicine and Rehabilitation, 90*(11), 1880-1886. doi:10.1016/j.apmr.2009.06.017

Wall, Nicholas R., De La Parra, M., Callaway, Edward M., & Kreitzer, Anatol C. (2013). Differential Innervation of Direct- and Indirect-Pathway Striatal Projection Neurons. *Neuron, 79*(2), 347-360. doi:10.1016/j.neuron.2013.05.014

Widnell, K. (2005). Pathophysiology of motor fluctuations in Parkinson's disease. *Movement Disorders, 20*(S11), S17-S22. doi:10.1002/mds.20459

Wielinski, C. L., Erickson-Davis, C., Wichmann, R., Walde-Douglas, M., & Parashos, S. A. (2005). Falls and injuries resulting from falls among patients with Parkinson's disease and other parkinsonian syndromes. *Movement Disorders, 20*(4), 410-415. doi:10.1002/mds.20347

Wittwer, J. E., Webster, K. E., & Hill, K. (2013). Music and metronome cues produce different effects on gait spatiotemporal measures but not gait variability in healthy older adults. *Gait Posture, 37*(2), 219-222. doi:10.1016/j.gaitpost.2012.07.006

Yelnik, J. (2002). Functional anatomy of the basal ganglia. *Movement Disorders, 17*(S3), S15-S21. doi:10.1002/mds.10138

Yogev, G., Giladi, N., Peretz, C., Springer, S., Simon, E. S., & Hausdorff, J. M. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: which aspects of gait are attention demanding? *Eur J Neurosci, 22*. doi:10.1111/j.1460-9568.2005.04298.x

Zatorre, R. J. (2015). Musical pleasure and reward: mechanisms and dysfunction. *Ann N Y Acad Sci, 1337*, 202-211. doi:10.1111/nyas.12677

Zhu, M., Li, M., Ye, D., Jiang, W., Lei, T., & Shu, K. (2016). Sensory symptoms in Parkinson's disease: Clinical features, pathophysiology, and treatment. *Journal of Neuroscience Research, 94*(8), 685-692. doi:10.1002/jnr.23729

Chapter 2

2 General Protocol

The purpose of this chapter is to summarize the common procedures used among all three studies in this dissertation. Although each study examines a different population and includes slight protocol variations (outlined in the individual chapters), the protocol for gait trials, stimulus selection, demographic assessment, and beat perception ability assessment are consistent across studies and summarized below.

In general, the studies aimed to test the effects of different musical features (e.g., groove) in auditory stimuli on the gait of different populations (younger adults, older adults, people with PD). The immediate effects of instructions to synchronize or to walk freely to the auditory stimuli were compared between those with good beat perception and with poor beat perception in each of the populations. Thus, each session generally consisted of baseline gait measurement, collection of stimulus ratings (to select individualized stimuli), cued gait measurements, and assessment of beat perception ability.

2.1 Baseline Gait Measurements

To acquire baseline gait data, participants walked eight passes of a 16-foot pressure sensitive walkway (Zeno^{TM}) in silence, at a self-selected and comfortable walking pace. Baseline trials were performed prior to hearing any auditory stimuli. To limit capture of acceleration/deceleration phases of gait and capture steady-state walking, participants began each trial 1.78 meters (m) from the start of the walkway (Hollman et al., 2010; Rennie et al., 2018). Participants were instructed to walk continuously between two floor markings marked 1.78 m from each end of the walkway until instructed to stop (Figure 2.1).

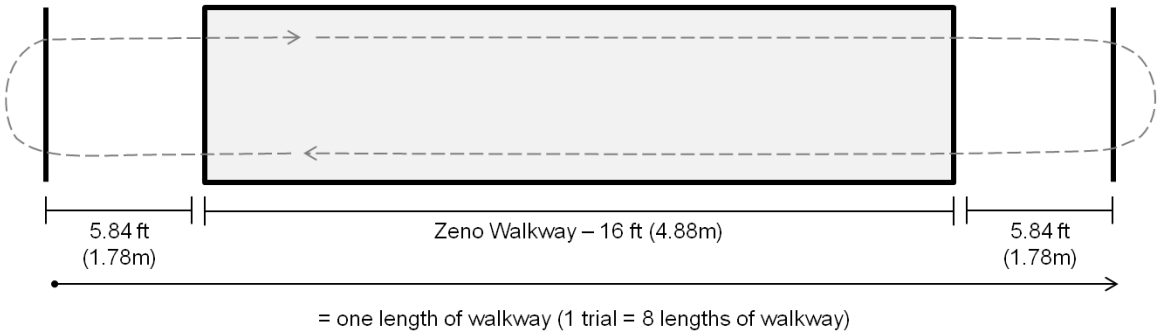


Figure 2.1: Illustration of the pressure sensitive Zeno^{TM} walkway procedures. All gait trials consisted of eight consecutive passes of the walkway (shaded grey rectangle). To reduce acceleration/deceleration effects, participants walked to a floor marking 1.78m beyond the edge of the walkway (solid black lines) before turning and re-entering the walkway.

2.2 Selection of Auditory Stimuli.

In each study, participants walked to an individualized list of stimuli that were chosen based on their own ratings of familiarity and groove. To create the list, participants listened to and rated selections from a database of non-lyrical music clips (30 seconds each). Different databases were used for younger and older adults to ensure appropriate familiarity with songs and genres, and specific database features are outlined in the respective experimental chapters. Stimulus ratings were piloted in the appropriate age groups to ensure that they elicited reliable ratings within a group. To make the stimuli suitable for walking, they were digitally altered so that the stimulus tempo (beats per minute) was slightly faster than the participant's walking pace: specifically, 15% faster for younger and older adults, and 10% faster for PD participants. Tempo alteration was achieved using Audacity® Sound Editing Software (http://audacity.sourceforge.net), and pitch was preserved. Participants listened to adjusted music clips in a randomized order and rated each song based on familiarity, groove, enjoyment, and beat salience. All four ratings were made before moving onto the next stimulus. Stimuli were presented over noise canceling headphones (Bose® Quiet Comfort 3) and were rated on a computerized 100-pt Likert scale (Table 2.1). Stimuli and ratings scales were presented via LabVIEW (National Instruments, Austin, TX). For the purpose of this

dissertation, enjoyment and beat salience ratings were included only as filler ratings and were not analyzed. Using familiarity and groove ratings, eight stimuli were selected for each participant for the following cueing conditions:

(1) high groove/high familiarity,

(2) high groove/low familiarity,

(3) low groove/high familiarity,

(4) low groove/low familiarity.

A custom written MATLAB script selected two songs for each condition based on ratings that maximized the above listed combinations. This resulted in a total of 8 songs. Finally, for two metronome-only trials, a metronome file (www.reztronics.com) was adjusted to a tempo faster than each participant's baseline walking cadence (15% faster for younger and older adults, 10% faster for PD participants).

Table 2.1 End anchors for familiarity, groove, enjoyment, and beat salience ratings. Bold-faced text was not presented to participants.

Familiarity: "How familiar is the piece of music to you?"	
1 = Never heard it before	100 = Know this song so well that I can predict what happens next
Groove: "How much does this piece of music make you want to move?"	
1 = Would definitely not move to this	100 = Would move a lot to this
Enjoyment: "How much do you enjoy listening to this piece of music?"	
1 = Strongly dislike this song	100 = Strongly enjoy this song
Beat Salience: "How strong is the beat in this piece of music to you?"	
1 = Very weak	100 = Very strong

2.3 Cued Walking Trials.

At the beginning of testing, participants were randomized to one of two instruction conditions: free-walking or synchronized-walking (Figure 2.2). Free-walkers were instructed to walk however felt most comfortable for them. In cases where participants queried if they should synchronize, they were instructed again to "walk however feels most comfortable". Synchronized-walkers were instructed to match their footsteps to the beat in the piece of music as best as possible and to take time to find the beat before beginning their walk. Walking on the spot prior to beginning was permitted. Synchronized-walkers were instructed that the beat rate should be relatively similar to their silent walking rate and that they should not have to walk half of or double their normal walking rate to synchronize.

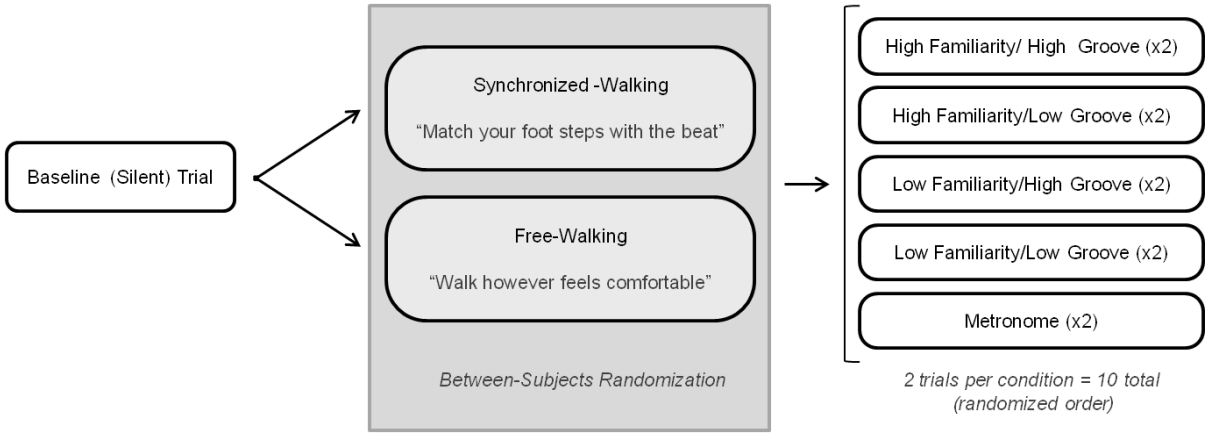


Figure 2.2 Illustration of procedures for cued walking trials.
Adapted from Ready et al. (2019). Gait was evaluated in silence (baseline – no RAS) and during five randomly ordered RAS conditions: listening to music that was rated by the participant as (1) high groove/high familiarity, (2) high groove/low familiarity, (3) low groove/high familiarity, (4) low groove/low familiarity, and (5) a metronome. Two trials occurred for each condition with distinct stimuli, with the exception of metronome which was identical in both trials. Participants were randomized to either synchronized-walking (instructed to match their steps with the beat in the auditory cue) or free-walking (instructed to walk however was comfortable, with the cue in the background).

Participants completed two gait trials for each of the 5 cueing conditions in a randomized order, for a total of 10 trials (8 music trials, 2 metronome trials). Cued trials followed the same protocol as baseline gait trials (Figure 2.1), with 8 passes along the walkway for each trial.

Stimuli were played over wireless Sennheiser ® HDR 160 headphones worn by the participant, at a comfortably audible level, to prevent the experimenter from inadvertently influencing the participant.

2.4 Demographics

A demographics questionnaire was delivered in two parts before and after cued gait trials. Following the rating task but prior to cued walks, participants completed a section regarding sex, education, etc. (Appendix A). The second half of the questionnaire, about music and dance training (Appendix B) was completed following cued gait trials. The questionnaire was delivered in two parts to provide participants with a task to complete while the experimenter processed the baseline walking data and stimuli selections for cued gait trials. Additionally, this prevented the possibility that questions regarding music or dance training would influence participant performance during the experiment. Questionnaires were presented to participants over Qualtrics, a confidential online survey platform (Qualtrics, 2018).

2.5 Beat Alignment Test (BAT)

Lastly, participants completed the Perception Subtest of the Beat Alignment Test (BAT) from the Goldsmiths Musical Sophistication Index v1.0 (Müllensiefen, Gingras, Stewart, & Musil, 2014) to measure beat perception ability. Participants listened to a series of instrumental music clips (3 practice trials, 17 test trials) with a metronome beep superimposed over the music, and judged whether the metronome was on or off the beat by indicating “Y” (yes, on the beat) or “N” (no, off the beat) on the keyboard. Tones were correctly aligned (i.e., on beat) in 4 trials, at a slower or faster rate than the beat rate (i.e., period-shifted) in 8 trials, or misaligned but at the correct tempo (i.e., phase-shifted) in 5 trials. Trial order was randomized and participants were instructed to make judgments based only on listening and not by tapping in time with the music.

Beat perceivers were categorized as poor if they scored at or below the mean accuracy percentage (64.7%, 66.4%, 66.3% respectively for healthy young adults, healthy older adults, and PD participants). Therefore, participants were considered poor beat perceivers if they scored ≤ 11 of 17 trials correctly (or ≤ 64.71% accuracy) and good beat perceivers if they

scored ≥ 12 of 17 trials correctly (or ≥70.6% accuracy). This cut off is in line with previous literature using the BAT in auditory cueing studies (Leow et al., 2014) and with other means and medians from a larger, unpublished, sample of BAT data from the Music & Neuroscience Lab (HYA n = 277, HOA n = 147, PD n = 48).

2.6 Data Processing

Individual gait trials were automatically processed in the ProtoKinetics Movement Analysis Software Package (Protokinetics LLC, Havertown, PA) and reviewed by the experimenter for errors (e.g., incorrect identification of left or right foot falls, identifying two footfalls as one). Custom written MATLAB scripts were used to calculate trial means for each dependent variable after excluding footfalls at each end of the mat in which less than ¾ of a full foot was on the mat. This exclusion was done to prevent errors in step length calculations. Mean values of each dependent variable were calculated trial-by-trial for each participant and averaged across conditions for each participant in Microsoft Excel.

2.7 Data Analysis

Separate 4-way mixed design analyses of variance (ANOVAs) were conducted on each dependent variable (DV) using SPSS (version 22). Within-subject variables included familiarity (high, low) and groove (high, low). Between-subject factors included instruction (synchronize, walk freely) and beat perception ability (poor, good). To assess spatial changes, the dependent variables step length and stride width were examined. To assess changes in gait timing, the dependent variables cadence (steps per minute), stride velocity, and double-limb support time (DLST; seconds with both feet on the ground) were examined. Additionally, DLST and stride width were also analyzed as indicators of stability (Hausdorff et al., 1998). Finally, gait variability was assessed using the coefficients of variation (standard deviation divided by the mean) for step length, step time, and stride velocity. Family-wise Bonferroni adjustments were applied for the following families of DVs:

1. Spatial (step length, stride width)
2. Temporal (cadence, stride velocity, double-limb support time)

3. Variability (coefficient of variation [CV] for step length, step time, stride velocity).

Thus, critical p values are, respectively, 0.025 (spatial); 0.017 (temporal); and 0.017 (variability).

To account for individual differences (e.g., in leg length or height), analyses were performed on normalized change scores, which represent proportional changes from one's baseline gait parameters. To do this, the baseline gait parameter (for example, silent walking step length) subtracted from the cued gait parameter of a given condition (e.g., high groove step length); this is then divided by the baseline gait parameter (silent walking step length):

$$Normalized\ Change\ Score = \frac{(cued\ gait\ parameter - baseline\ gait\ parameter)}{baseline\ gait\ parameter}$$

References

Hausdorff, J. M., Cudkowicz, M. E., Firtion, R., Wei, J. Y., & Goldberger, A. L. (1998). Gait variability and basal ganglia disorders: stride-to-stride variations of gait cycle timing in Parkinson's disease and Huntington's disease. *Mov Disord, 13*. doi:10.1002/mds.870130310

Hollman, J. H., Childs, K. B., McNeil, M. L., Mueller, A. C., Quilter, C. M., & Youdas, J. W. (2010). Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. *Gait & Posture, 32*(1), 23-28. doi:https://doi.org/10.1016/j.gaitpost.2010.02.017

LabVIEW. (2014). National Instruments: Austin, Texas, USA.

Leow, L.-A., Parrott, T., & Grahn, J. A. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Protokinetics Movement Analysis Software (2014). Havertown, PA, USA.

Qualtrics. (2018). Provo, Utah, USA.

Rennie, L., Löfgren, N., Moe-Nilssen, R., Opheim, A., Dietrichs, E., & Franzén, E. (2018). The reliability of gait variability measures for individuals with Parkinson's disease and healthy older adults – The effect of gait speed. *Gait & Posture, 62*, 505-509. doi:https://doi.org/10.1016/j.gaitpost.2018.04.011

Chapter 3

3 Accelerated Music-Based RAS in Healthy Young Adults

Rhythmic auditory stimulation (RAS) is a strategy commonly used to regulate walking patterns among people with gait impairment. Auditory cues provide a consistent, rhythmic structure to cue the timing of steps as people synchronize their footfalls to the onset of beats in an auditory cue (e.g., metronome or piece of music). Synchronizing to cues can increase walking speed, stride length, or gait regularity (Lim et al., 2005; Thaut & Abiru, 2010).

This is particularly helpful in conditions such as PD that are characterized by gait irregularity and slowness. For this reason, cues are frequently delivered proportionally faster than a person's walking rate (e.g., played at a tempo 15% faster than the person's natural walking rate) with the intention of cueing a faster gait speed. Benefits have been observed among healthy young adults and people with PD when cueing gait at these accelerated tempi. Specifically, cues that are faster than a person's natural or preferred walking rate are associated with increases in velocity but not stride length (Ghai, Ghai, & Effenberg, 2018a; Ghai, Ghai, Schmitz, & Effenberg, 2018b). In contrast, cues that are slower than preferred walking rate are associated with increased stride length but not increased velocity (Ghai et al., 2018a; Ghai et al., 2018b).

The effects of auditory cueing vary and may depend in part on individual rhythmic abilities (Dalla Bella et al., 2017; Leow et al., 2014; Ready et al., 2019). For example, poor beat perceivers walk more slowly than good beat perceivers when told to synchronize (Leow et al., 2014). Moreover, poor beat perceivers widen their stance, potentially to increase stability, when told to synchronize (Ready et al., 2019). These findings suggest that synchronized walking to auditory cues may compromise gait in certain populations, and that more stable gait may be achieved by tailoring task instructions (e.g., whether to synchronize or not) to the individual.

Much like the variability that different instructions elicit, variability is observed in response to different music. Music perceived to be higher in groove (i.e., music that produces a strong desire to move) results in faster gait with larger strides than music that is perceived to be

lower in groove, both when cueing proportionally faster rates (Leow 2014, 2015) and preferred walking rate (Ready et al., 2019). In particular, low groove stimuli produce negative effects, such as slower and/or more variable gait, which are worse when synchronizing (Ready et al., 2019), and are worse for poor versus good beat perceivers (Leow et al. 2014). Importantly, greater step-to-step variability is associated with higher fall risk and would represent an undesirable gait outcome (Callisaya et al., 2011).

Although the impact of instructions to synchronize on good/poor beat perceivers has been demonstrated at both preferred and accelerated cueing rates (Leow et al., 2014; Leow et al., 2018; Ready et al., 2019), the relationship among beat perception ability, musical groove and instructions to synchronize has only been demonstrated in groups cued at preferred pace (Ready et al., 2019). Synchronization demands may be higher when cued at a tempo faster than baseline; consequently, a faster pace may yield different findings. The aim of this study is to explore the impact of instructions (synchronize versus no instruction), beat perception (good versus poor), and groove (high versus low) on gait outcomes in healthy young adults when cued at an accelerated tempo (15% faster than baseline walking). Familiarity with the music was also manipulated (high versus low familiarity) to replicate previous approaches to RAS with conflicting results (Leow et al., 2015, Ready et al., 2019). It was hypothesized that high groove cues would produce better overall gait performance than low groove cues (faster, longer strides with better stability). In addition, poor beat perceivers were expected to demonstrate faster and more stable gait with instructions to walk freely (fewer cognitive demands) instead of to synchronize. Finally, higher familiarity cues (compared to low familiarity) were expected to reduce negative impacts of synchronizing on gait by reducing the cognitive demands associated with predicting beat onset.

3.1 Methods

3.1.1 Participants

107 healthy young adults were recruited for this study from the University of Western Ontario using the undergraduate psychology student pool or study flyers on campus. 10 data sets were incomplete due to technological error resulting in loss of beat perception data or participants not allocating time for the full study. An additional 11 participants were excluded from

analyses due to stimulus manipulation error, resulting in a final sample of 86 participants. All participants were compensated for their time and provided written informed consent, as per the Nonmedical Research Ethics Board (see Appendix C for ethics approval and the letter of information). Demographic data is available in Table 2.1.

Table 3.1. Participant demographics.

	Free Walking		Synchronized Walking	
	Poor (n = 20)	Good (n = 25)	Poor (n = 22)	Good (n = 19)
Age	21.1 (4.8)	20.4 (3.4)*	21.3 (3.1)	20.8 (4.1)
Gender (male/female)	6/13*	14/11	9/13	5/14
Music training (years)	3.7 (3.9)	5.0 (3.8)	5.2 (4.7)	3.9 (3.5)
Dance training (years)	3.4 (5.3)	2.0 (4.1)	2.9 (3.5)	2.6 (3.8)

Note. Data presented as means (standard deviations) for age, music training, and dance training. Sums are presented for gender (male/female). *One participant did not report this item.

3.1.2 Stimuli

Chapter 2 (General Methods) outlines the procedures regarding stimuli selection across all three gait studies in this dissertation. The stimuli used for the younger adult population in this study are available in Appendix D.

3.1.3 Procedure

Participants in this study followed the procedures outline in Chapter 2 (General Methods). The entire testing session lasted for approximately two hours.

3.1.4 Data Analysis

As indicated in Chapter 2, separate 4-way mixed design ANOVAs were conducted on normalized change scores for each dependent variable using SPSS (version 22) as initial analyses with familiarity (high, low), and groove (high, low), instruction (synchronize, walk freely) and beat perception ability (poor, good) as factors. The following families of spatiotemporal gait parameters were assessed as dependent variables. Family-wise Bonferonni adjustments were applied as follows:

1. Spatial (step length, stride width)

2. Temporal (cadence, stride velocity, double-limb support time)
3. Variability (CV for step length, step time, stride velocity).

Thus, critical *p*-values are as follows: 0.025 (spatial); 0.017 (temporal); and 0.017 (variability).

Several dependent variables yielded no significant or only marginally significant effects of familiarity or beat perception ability (all dependent variables but DLST). When this was the case, analyses were collapsed across these variables, and the resulting 2x2 ANOVAs are reported in the results with the variables instruction type (free walking, synchronized walking) and groove (low groove, high groove). The original 4-way analyses including familiarity and beat perception ability are available in Appendix E for completeness.

For each dependent variable, additional ANOVAs were run on raw data (available in Table 3.2) to determine if cueing altered gait significantly from baseline. Bonferonni adjusted critical *p*-values, as reported above, were applied to these analyses. For all dependent variables except DLST 2 (instruction: free, synchronized) x 4 (cueing condition: baseline [no cue], low groove, high groove, metronome) ANOVAs were run. For DLST, a 3-way ANOVA with beat perception ability (good, poor), instruction type (free, synchronized), and cueing condition (baseline [no cue], high familiarity/high groove, high familiarity/low groove, low familiarity/high groove, low familiarity/low groove) was run. No interactions between cueing condition and beat perception ability, or levels of familiarity, were present; thus, the values reported in Table 3.2 are averaged across these variables**.** For completeness, complete raw data for DLST is available in Appendix F.

Table 3.2 Raw means and standard deviations for stimulus and instruction conditions.

	Baseline	Low Groove	High Groove	Metronome
Step Length (cm)				
Free Walking	64.9 (5.7)	63.4 (5.1)***	64.3 (5.3)	63.2 (5.3)***
Synchronized Walking	64.4 (6)	61 (5.9)***	63.8 (6.1)	62 (7.1) **
Stride Width (cm)				
Free Walking	9.2 (2.9)	8.9 (3)	8.9 (3)	9.1 (2.9)
Synchronized Walking	8.7 (2.7)	9.2 (2.9)*	9 (2.7)	9.4 (2.9)***
Cadence (steps/min)				
Free Walking	110.1 (7.8)	108.7 (8.6)	111.2 (8.6)	110.2 (9.6)
Synchronized Walking	110 (8.6)	109.2 (13.1)	118.5 (9.2)***	120.5 (8.9)***
Stride Velocity (cm/sec)				
Free Walking	119.3 (15.5)	115 (15.1)**	119.4 (15.8)	116.1 (15.8)*
Synchronized Walking	117.9 (14.6)	111.5 (19.7)**	125.9 (15.8)***	124.3 (17.1)***
Double-Limb Support Time (sec)				
Free Walking	12.2 (1.3)	12.6 (1.4)***	12.4 (1.4)*	12.6 (1.5)***
Synchronized Walking	12.2 (1.6)	12.8 (1.5)***	12.1 (1.5)	12.1 (1.5)
Step Length Variability (CV)				
Free Walking	3.9 (1.6)	3.4 (1)	3.6 (1.1)	3.6 (1)
Synchronized Walking	3.7 (0.9)	4.5 (1.8)**	4.3 (1.3)**	4.2 (1.3)
Step Time (CV)				
Free Walking	3 (1)	2.9 (0.7)	2.9 (0.9)	3 (0.8)
Synchronized Walking	3 (0.7)	4.7 (2.6)***	3.7 (1.1)*	3.3 (0.6)
Stride Velocity (CV)				
Free Walking	4.1 (1.7)	3.3 (1.1)***	3.5 (1.2)**	3.4 (1)**
Synchronized Walking	3.9 (1.3)	4.8 (2.3)*	4 (1.3)	3.6 (1)

Note. Raw values for each dependent variable are averaged across beat perception ability and familiarity. Reported effects are significant at the family-wise corrected alpha levels reported in the study methods (Chapter 2). Pairwise comparisons with baseline were completed within instruction groups as stimulus type interacted with instruction type for all DVs. DLST stimulus type did not interact with beat perception or familiarity, thus comparisons within instruction group and stimulus type are reported. *Significant at $p < .05$. ** $p < .01$. *** $p < .001$.

3.2 Results

3.2.1 Spatial Gait Parameters

Step Length (cm).

Overall, steps tended to shorten in comparison to baseline with cueing. A main effect for stimulus [F (1.8, 152.5) = 29.8, p = .001, $np2$ = .26] indicated that steps shortened less with high groove cues [M = -.008, SD = 0.05) than with metronome [M = -.03, SD = .06] and low groove cues (M = -0.036, SD = 0.06). This significant main effect is qualified by an interaction between groove and instruction [F (1, 84) = 20.2, p < .001, $np2$ = .19]. Although both synchronized and free walkers took significantly larger steps with high groove compared to low groove [Synchronized: t (40) = 7.0, p < .001; Free: t (40) = -7.7, p < .001] and metronome cues [Synchronized: t (44) = -5.6, p < .001; Free: t (40) = -5.1, p < .001], follow-up t-tests indicated that synchronized walkers shortened their steps significantly more during low groove cueing than free walkers did [t (84) = 2.52, p < .01]. See Table 3.2 for descriptive statistics.

Stride Width (cm).

No significant main effects were present for groove, familiarity, or beat perception ability after Bonferonni correction. A significant main effect of stimulus type [F (1.7, 141.2) = 9.85, p = .01, $np2$ = .06] indicates that strides widened significantly more with metronome cues [M = .05, SD = .02] than both high groove [M = .01, SD = .02] and low groove cues [M = .01, SD = .02]. Additionally, a significant main effect of instruction type [F (1, 84) = 7.41, p < .01, $np2$ = .08] indicating that synchronized walkers used a significantly wider stance (M = 0.07, SD = 0.17) than did free walkers (M = -0.01, SD = 0.14). See Table 3.2 for descriptive statistics.

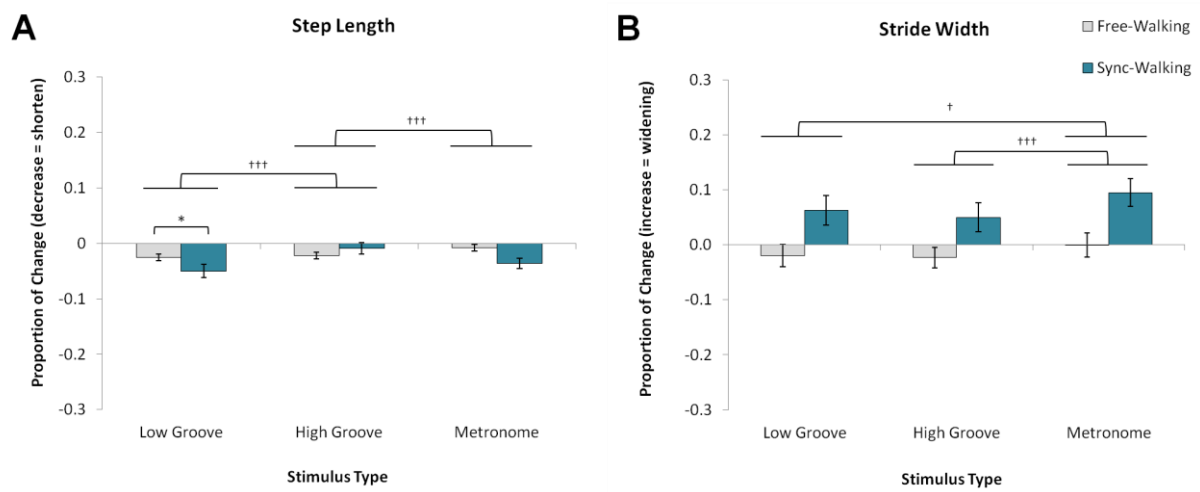


Figure 3.1. Mean normalized changes scores and standard error for spatial gait measures.
(A) Step length and (B) stride width are shown for stimulus and instruction types. *Denotes significant interactions between stimulus and instruction types at p <.05. ††† Denotes effects of stimulus type across *both* instruction groups at p < .001. † Denotes significance at p < .05.

3.2.2 Temporal Gait Parameters

Cadence (steps/minute).

A significant main effect of stimulus [F (1.3, 110.6) = 53.8, p < .001, $np2$ = .39] indicated that participants walked at a faster rate (i.e., with more steps per minute) to high groove (M = 0.045, SD = 0.06) and metronome cues (M = .047, SD = .07) than low groove cues (M = -0.01, SD = 0.08). A significant main effect of instruction [F (1, 84) = 28.2, p < .001, $np2$ = .25] indicated that synchronized walkers [M = 0.06, SD = 0.06] took more steps per minute than free walkers [M = 0.00, SD = 0.04]. Both main effects are qualified by a significant stimulus by instruction interaction [F (1.3, 110.6) = 27.0, p < .001, $np2$ = .24]. Both groups walked with significantly higher cadence to high groove (Synchronized: M = 0.08, SD = .06; Free: M = 0.01, SD = 0.05) and metronome (Synchronized: M = .10, SD = .05; Free: M = .001, SD = .05) than low groove cues (Synchronized: M = -0.01, SD = 0.11; Free: M = -0.01, SD = 0.04). However, synchronized walkers increased cadence during high groove conditions significantly more than free walkers [t (84) = -6.31, p < .001]. Additionally, the highest average proportional change from baseline was 0.1 (or 10%) among synchronized walkers

during metronome cueing. A normalized change score increase of 0.15 or 15% would correspond to matching the cued tempo, therefore synchronized walkers were not matching their steps per minute to the tempo. No significant effects for familiarity or beat perception ability were observed. See Table 3.2 for descriptive statistics.

Stride Velocity (centimeters/second).

High groove cues [*M* = .03, *SD* = .08] elicited significantly faster stride velocity than both metronome [*M* = .01, *SD* = .09] and low groove cues [*M* = -.04, *SD* = .1], as indicated by a significant main effect for stimulus [*F* (1.7, 146.2) = 58.1, *p* < .001, *np2* = .41]. This was qualified by a significant stimulus by instruction interaction [*F* (1.7, 146.2) = 25.1, *p* < .001, *np2* = .23]. Follow-up t-tests indicated significantly faster stride velocity among synchronized walkers vs. free walkers during high groove conditions [*t* (84) = -4.27, *p* < .001]. Synchronized and free walkers did not differ during low groove cueing [*t* (84) = 0.98, *p* > .05). See Table 3 for descriptive statistics.

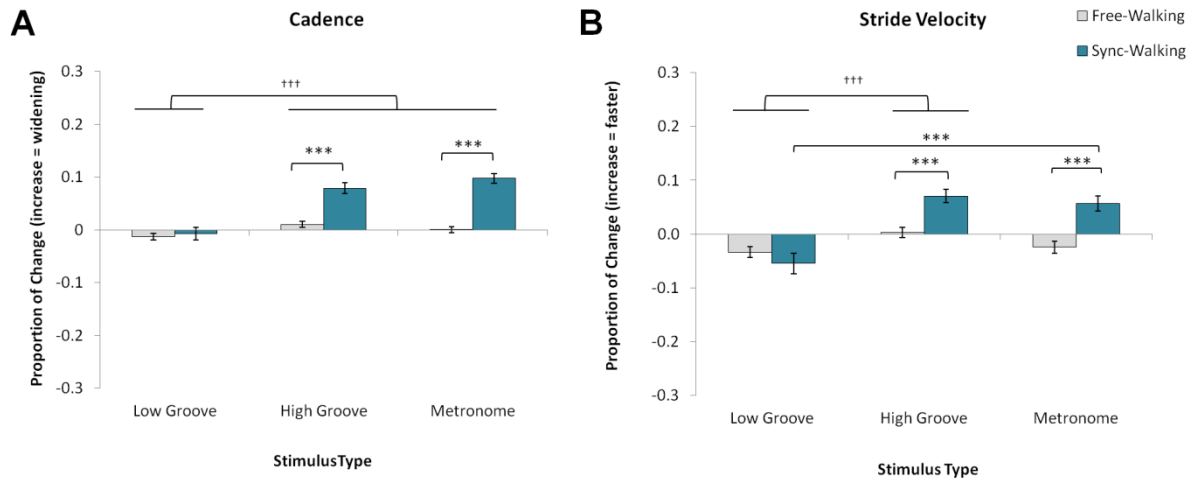


Figure 3.2. Mean normalized change scores and standard error for temporal measures.
(A) cadence and (B) stride velocity are shen between stimulus and instruction types. ***Denotes significant interactions between stimulus and instruction types at *p* <.001. ††† Denotes effects of stimulus type across *both* instruction groups at *p* < .001.

Double-Limb Support Time (DLST; seconds)

The 4-way ANOVA yielded a significant main effect of groove [F (1, 82) = 75.9, p < .001, $np2$ = .48], indicating that low groove cues elicited significantly longer DLST [M = 05, SD = .06] than high groove cues [M = .00, SD = .06]. This was qualified by a significant groove by instruction interaction [F (1, 82) = 18.1, p < .001, $np2$ = .18] in which synchronized walkers appeared to increase DLST more than free walkers with low groove cues, however follow-up t-tests did not yield any significant differences between instruction groups.

This was qualified by an additional three-way interaction for beat perception ability, groove, and familiarity [F (1, 82) = 7.00, p < 0.05, $np2$ = .08]. Follow-up t-tests indicated that this is driven by differences between good and poor beat perceivers during high familiarity conditions. Specifically, good beat perceivers demonstrated no significant differences in DLST between high and low groove cues that were high in familiarity [t (88) = 1.48, p > .05], whereas poor beat perceivers reduced their DLST when walking to high groove cues that are high in familiarity (in comparison to low groove cues that are high in familiarity) [t(80) = 4.06, p < .001].

Finally, an additional 2x2x5 mixed-design ANOVA was completed to determine if metronome cues differed from any music cueing conditions, and if instructions or beat perception ability influenced this. Beat perception (good, poor), instructions (synchronize, walk freely), and stimulus type (low familiarity/low groove, low familiarity/high groove, high familiarity/low groove, high familiarity/high groove, and metronome) were included in the model. A stimulus by instruction interaction was significant [F (3.5, 283.7) = 11.23, p < .001, $np2$ = .12]. Follow-up t-tests indicated that synchronized walking with metronome cues elicited shorter DLST than low groove cues, both when low [t (40) = -5.8, p < .001] and high in familiarity [t (40) -5.4, p <.001]. DLST for metronome cues did not differ for any high groove cues, regardless of familiarity [low familiarity: t (40) = 0.3, p > .05; high familiarity t (40) = .3, p < .05]. In contrast, free walking with metronomes elicited shorter DLST compared to high groove [low familiarity: t (44) = 3.1, p < .01; high familiarity: t (44) = 3.1, p < .01] but not low groove cues [low familiarity: t (44) = -.4, p > .05; high familiarity: t (44) = -.9, p >.05]. See Table 3.2 for descriptive statistics.

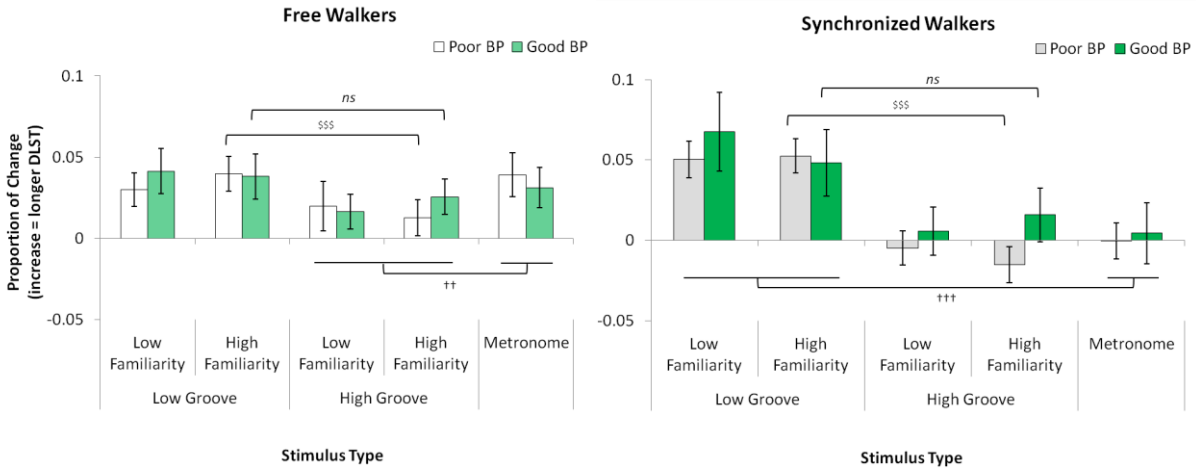


Figure 3.3. Mean normalized change scores and standard error for DLST among all stimulus types, beat perception groups, and instruction groups.
$$$ Denotes significant interaction among familiarity, groove, and beat perception ability (at $p < .001$) across instruction groups. ††† Denotes a significant interaction between stimulus and instruction type (at $p < .001$) across beat perception groups. †† Denotes significance at $p < .01$. *ns* = non significant. BP = beat perceivers.

3.2.3 Variability Gait Parameters

Step Length CV

No significant effects were found for stimulus, familiarity, or beat perception ability. A main effect of instruction [F (1, 84) = 11.3, p =.001, $np2$ = .12] indicated that free walkers exhibited lower step length variability (M = -0.02, SD = 0.24) than synchronized walkers (M = 0.22, SD = 0.48). See Table 3.2 for descriptive statistics.

Step Time CV

A significant main effect of instruction type [F (1.5, 112.4) = 15.0, p <.001, $np2$ = .15] indicated greater overall variability among synchronized walkers versus free walkers. An interaction between stimulus and instruction [F (1.3, 112.4) = 19.4, p <.001, $np2$ = .19] qualified this main effect. Follow-up t-tests demonstrated that, unlike free walkers, low groove cues were associated with higher variability for synchronized walkers than were both high

groove [$t(40) = 3.6$, $p < .001$] and metronome cues [$t(40) = -3.0$, $p < .01$] . Variability did not differ among cues for free walkers. See Table 3.2 for descriptive statistics.

Stride Velocity CV

A significant main effect of stimulus [F (1.7, 114.2) = 8.3, p = .001, $np2$ = .09] indicated that velocity variability was lower for high groove [M = -.04, SD = .34] and metronome [M = .002, SD = .37] compared to low groove cues [M = .08, SD = .48]. An additional main effect of instruction was observed [F (1, 84) = 11.0, p = .001, $np2$ = .12] indicated greater variability in stride velocity among synchronized walkers [M = .14, SD = .48] than free walkers [M = -.10, SD = .28].

These main effects were qualified by a significant stimulus by instruction interaction [F (1, 84) = 11.1, p =.001, $np2$ = .12]. Follow-up t-tests indicated that synchronized walkers exhibited more variability than free walkers during both low groove [t (84) = -4.6, $p < .001$] and high groove [t (84) = -2.7, $p < .05$] but not metronome cueing [t (84) = -1.3, $p > .05$]. Among synchronized walkers, low groove cues elicited greater variability than both high groove [t (40) = 3.0, $p < .01$] and metronome cues [t (40) = -4.4, $p < .001$]. See Table 3.2 for descriptive statistics.

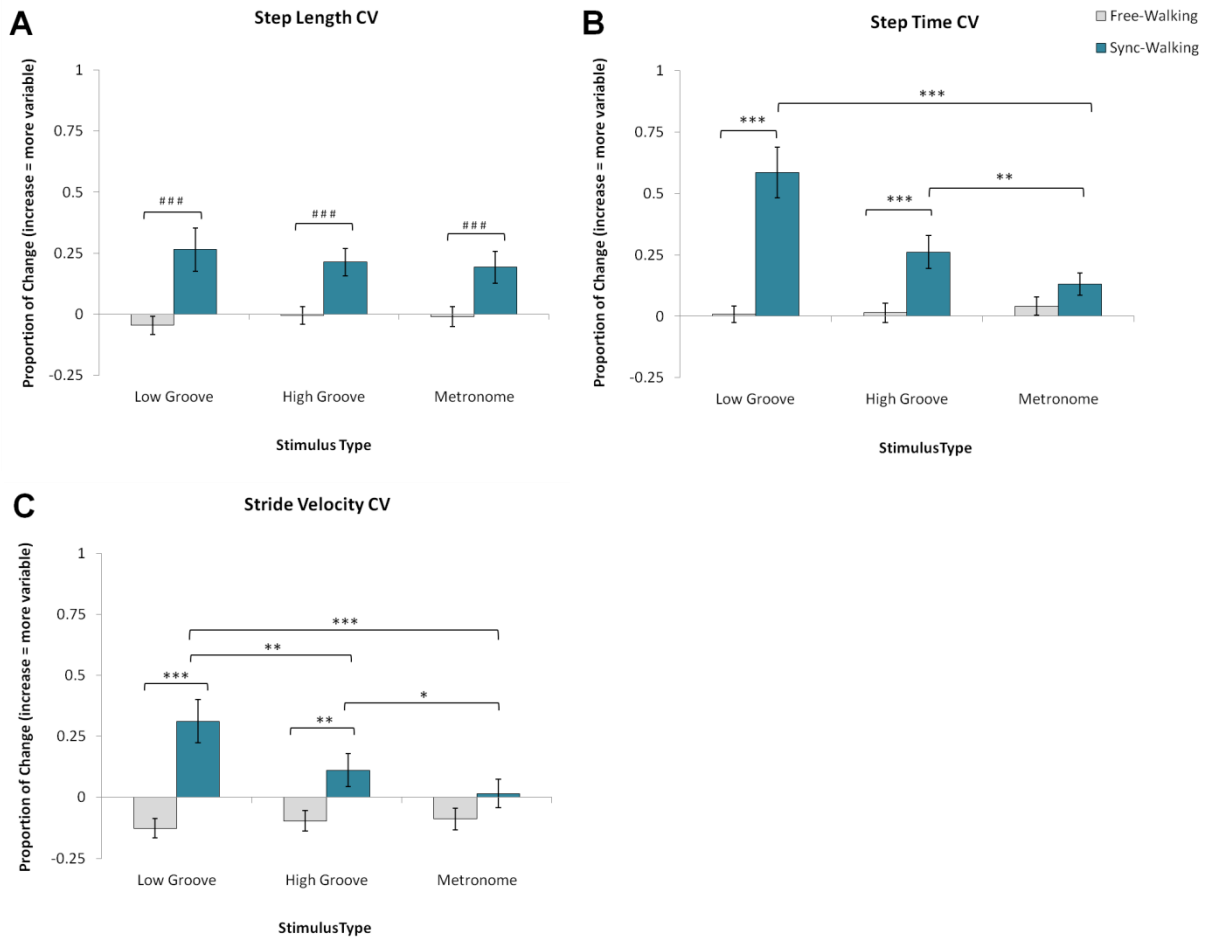


Figure 3.4. **Mean normalized change scores and standard error for variability measures. (A) step length CV, (B) step time CV, and (C) stride velocity CV are shown between stimulus and instruction types. *** Denotes significant interactions between stimulus and instruction at $p < .001$. ** Denotes significance at $p < .01$. * Denotes significance at $p < .05$. ### Denotes significant main effects of instruction type (across stimulus type) at $p < .001$.**

3.3 Discussion

The current study examined the relationship among musical groove, stimulus familiarity, and instructions to synchronize in good and poor beat perceivers during accelerated music-based RAS. When walking to cues 15% faster than self-selected walking pace, healthy young adults demonstrated changes in similar directions both when synchronizing to the beat and when walking freely. For example, both groups increased stride velocity regardless of instruction. However, these effects were made more extreme in the presence of instructions to synchronize

(i.e., synchronized walkers increased gait velocity even more than free walkers). These effects were minimally influenced by beat perception ability and stimulus familiarity. Overall, healthy young adults demonstrated longer step length and faster gait with high groove than low groove cues, but synchronized walkers increased step length and speed more than free walkers during high groove cueing. Notably, an increase in stride width was observed among synchronized walkers, in addition to greater variability for step length, stride time, and stride velocity. While increased step time and step velocity variability were more pronounced during low groove cueing, variability also increased during high groove cueing for synchronized walkers. Stance widening is often a compensatory strategy for instability (Donoghue, Cronin, Savva, O'Regan, & Kenny, 2013; Dunlap, Perera, VanSwearingen, Wert, & Brach, 2012; Gabell & Nayak, 1984), and greater gait variability is associated with higher fall risk (Hausdorff, Edelberg, Mitchell, Goldberger, & Wei, 1997; Hausdorff, Rios, & Edelberg, 2001). Therefore, this suggests that enhancements in step length and speed associated with synchronized RAS may come at a cost to stability. Instructions to synchronize may constrain dynamic balance and/or gait control relative to free-walking RAS. The finding of reduced stability and increased gait variability while synchronizing is not consistent with previous literature suggesting that poor beat perception creates dual-task interference while synchronizing (Leow et al., 2014; Leow et al., 2015). Given that increased stride width and gait variability were observed across both good and poor beat perceivers in the present study, it may also be that faster cue rates are more challenging to synchronize with for all participants, not just those who have difficulty perceiving a beat accurately.

3.3.1 High groove cues produce better gait outcomes than low groove cues

High groove and metronome cues were consistently associated with faster gait, lower DLST, and longer step length than low groove cues, indicating that high and low groove cues cannot be used interchangeably during RAS. These results are in line with previous findings indicating that high groove cues produce better gait outcomes than low groove cues (Leow et al., 2015; Ready et al., 2019). With regards to changes from baseline, high groove cues improved some gait parameters (cadence and velocity); however, low groove cues consistently negatively affected all aspects of gait (spatial, temporal, and several variability

measures). Step length decreased for both instruction groups when walking to low groove cues, stride velocity slowed, and variability increased for step length, stride time, stride velocity. Although high groove cues were consistently more beneficial than low groove cues, high groove cues in and of themselves may not improve all components of gait. Instead, using groove to maximize changes in gait speed with a cue pace that does not negatively impact gait stability appears important for optimizing RAS outcomes.

The purpose of cueing RAS users at a rate faster than preferred walking pace was to elicit faster gait velocity. Faster gait velocity can be achieved by increasing cadence and/or increasing step length. Importantly, velocity changes in RAS can be achieved with one or a combination of step length and cadence. Here, velocity increases were achieved through cadence adjustments, as users did not increase step length (from baseline) in any conditions. This is in line with other findings that accelerated RAS (i.e., faster than baseline cues) can increase velocity, but minimally impact step length, in both PD and healthy populations (Ghai et al., 2018a; Ghai et al., 2018b). Importantly, our findings indicate that accelerated tempi alone do not increase gait velocity, as the 15% faster low groove cues still produced lower velocity. Thus, perceived groove should be high to increase gait velocity during music-based RAS.

3.3.2 Potential impact of cueing on gait stability

Step-to-step variability relates to fall risk, with higher variability in stride time and stride length predicting future falls (Hausdorff et al., 1997; Hausdorff et al., 2001). Therefore, it is important to consider how cueing alters gait stability, as certain approaches to RAS increase gait variability and others do not. In this study, synchronized walking elicited higher step-to-step variability for length, time, and velocity but free walking did not. In both groups, low groove cues elicited higher variability than high groove cues.

One explanation for the greater variability among synchronized walkers is that the healthy young adults may demonstrate a ceiling effect for some gait parameters, given their already normal gait. Therefore, altering gait to attempt to match the music may have induced gait variability. Furthermore, cue rates may have been too fast for participants, and variability may have reflected difficulty determining how to match the tempo. Two previous music-based

RAS studies also found increased variability among healthy young adults when synchronizing to faster cueing rates of +15% and +22.5% (Leow et al., 2014; Leow et al., 2015). Both of the above explanations are supported by our finding that neither free walkers nor synchronized walkers demonstrated accurate tempo matching. On average (across individuals), the highest cadence increase was 10% among all synchronized walkers (who also exhibited the most variability) during high groove cues. However, to accurately match tempo, cadence would need to increase by 15%. While some individuals may have done this accurately, the synchronized group did not appear to uniformly hit the target. This may indicate that cues were too fast for most participants, particularly as they already had normal gait velocity, cadence, and step length.

3.3.3 Beat perception ability and familiarity

In the current study, minimal effects were observed for familiarity and beat perception ability. The literature regarding music familiarity in RAS is not entirely consistent, as Leow et al. (2015) found that highly familiar music produced faster and less variable gait than unfamiliar music when cueing at 15% over baseline, but Ready et al. (2019) found no effect of familiarity when cueing at baseline rate. The current study is consistent with the latter finding that familiarity has minimal impact on spatiotemporal gait parameters, despite cueing at accelerated rates as did Leow et al. (2015). Although the effects found by Leow and colleagues (Leow et al., 2015) were significant, the effect sizes were small and may not represent robust or clinically meaningful changes. Findings from the current study demonstrate that poor beat perceivers shorten their DLST with high groove/high familiarity cues compared to low groove/high familiarity cues, which was not the case for good beat perceivers who demonstrated consistent DLST across high and low groove cues that were highly familiar. Importantly, no findings from this study support the hypothesis that higher familiarity cues optimize gait performance among poor beat perceivers when synchronizing during RAS. While these findings do not support that gait can be meaningfully enhanced by familiarity, it supports that low levels of familiarity do not hinder gait, or negate the positive effects of RAS.

3.3.4 Walking pace is influenced by more than cue pace

The differences between high and low groove cues in the current study, together with previous findings (Leow et al., 2014; Ready et al., 2019), indicate that music-based RAS outcomes are heavily influenced by groove irrespective of cue pace. This is in line with other studies, which consistently find that groove is related to other types of bodily movement (Janata et al., 2012; Stupacher et al., 2013). Therefore, the influence of auditory stimuli on motor responses is increased by musical groove. In some cases, groove leads to greater effects on auditory-motor synchronization than other factors, such as beat perception ability or cue rate. There is limited understanding about what exactly produces the perception of groove, or urge to move with music. Particular musical properties are correlated with higher groove perception, for example, moderate rates of syncopation, repetitive rhythm, and lower bass frequencies in music (Janata, 2016; Stupacher et al., 2013). This study did not explore the underlying factors contributing to groove; therefore they were not assessed or manipulated. Future research exploring the impact of these different properties on gait may improve our understanding of how high groove music alters gait, and perhaps how to further manipulate musical properties to maximize gait outcomes.

3.4 Conclusions

The aim of this study was to examine the impact of perceived groove and familiarity on gait during music-based auditory cueing among young adults with good and poor beat perception, particularly in the presence or absence of instructions to synchronize to accelerated cues. This study suggests that perceived groove and instructions to synchronize significantly impact the gait outcomes observed. Specifically, high groove and metronome cues elicited better overall outcomes (longer, faster steps) than low groove cues. Instructions to synchronize enhanced these effects by producing faster gait velocity and higher cadence than was achieved with instructions to walk freely. Importantly, synchronizing to cues 15% faster than natural walking rate was associated with higher gait variability and wider strides. This may therefore suggest some consequences of synchronizing to fast auditory cues on gait stability. Finally, poor beat perceivers appeared to benefit from higher familiarity stimuli, as was evidenced by decreased DLST in these conditions, both when walking freely and when synchronizing. This may therefore suggest an overall benefit of using higher familiarity stimuli for poor beat

perceivers regardless of task demands. Overall, this study supports that higher perceived groove and instructions to synchronize foster greater temporal gait adjustments among good and poor beat perceivers, but suggests that further research is needed to determine how and why instructions to synchronize influence gait stability.

References

Dalla Bella, Benoit, Farrugia, Keller, Obrig, Mainka, & Kotz. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Sci Rep, 7*, 42005. doi:10.1038/srep42005

Donoghue, Cronin, Savva, O'Regan, & Kenny. (2013). Effects of fear of falling and activity restriction on normal and dual task walking in community dwelling older adults. *Gait & Posture, 38*(1), 120-124. doi:https://doi.org/10.1016/j.gaitpost.2012.10.023

Dunlap, Perera, VanSwearingen, Wert, & Brach. (2012). Transitioning to a narrow path: The impact of fear of falling in older adults. *Gait & Posture, 35*(1), 92-95. doi:https://doi.org/10.1016/j.gaitpost.2011.08.013

Gabell, & Nayak. (1984). The effect of age on variability in gait. *J Gerontol, 39*(6), 662-666.

Ghai, Ghai, & Effenberg. (2018a). Effect of Rhythmic Auditory Cueing on Aging Gait: A Systematic Review and Meta-Analysis. *Aging and disease, 9*(5), 901-923. doi:10.14336/AD.2017.1031

Ghai, Ghai, Schmitz, & Effenberg. (2018b). Effect of rhythmic auditory cueing on parkinsonian gait: A systematic review and meta-analysis. *Sci Rep, 8*(1), 506. doi:10.1038/s41598-017-16232-5

Hausdorff, Edelberg, Mitchell, Goldberger, & Wei. (1997). Increased gait unsteadiness in community-dwelling elderly fallers. *Arch Phys Med Rehabil, 78*. doi:10.1016/s0003-9993(97)90034-4

Hausdorff, Rios, & Edelberg. (2001). Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Arch Phys Med Rehabil, 82*. doi:10.1053/apmr.2001.24893

Janata, Tomic, & Haberman. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General, 141*(1), 54-75. doi:http://dx.doi.org/10.1037/a0024208

Leow, Parrott, & Grahn. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Leow, Rinchon, & Grahn. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *Annals of the New York Academy of Sciences, 1337*(1), 53-61. doi:10.1111/nyas.12658

Leow, Waclawik, & Grahn. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research, 236*(1), 99-115. doi:10.1007/s00221-017-5110-5

Ready, McGarry, Rinchon, Holmes, & Grahn. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait & Posture, 68*, 555-561. doi:https://doi.org/10.1016/j.gaitpost.2018.12.038

Stupacher, Hove, & Janata. (2016). Audio Features Underlying Perceived Groove and Sensorimotor Synchronization in Music. *Music Perception: An Interdisciplinary Journal, 33*(5), 571. doi:10.1525/mp.2016.33.5.571

Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller. (2013). Musical groove modulates motor cortex excitability: A TMS investigation. *Brain and Cognition, 82*(2), 127-136. doi:https://doi.org/10.1016/j.bandc.2013.03.003

Chapter 4

4 Accelerated Music-Based Auditory Cueing in Healthy Older Adults

Walking is a naturally rhythmic pattern; it follows a regular and repetitive cycle much like that of music. The rhythmic nature of gait and music has been capitalized on in the area of neurological rehabilitation to support natural and safe walking patterns among people experiencing gait disruptions. Playing rhythmic auditory cues, such as metronomes or music, provides temporal information to which a person can entrain their gait. Application of cues is most commonly seen in the areas of PD and stroke rehabilitation research.

Music may produce equivalent or better RAS outcomes than metronomes. Music can be motivating and enjoyable, thus facilitating adherence to RAS protocols (de Bruin et al., 2015). However, not all music appears to be interchangeable in terms of their effects on gait. Among healthy young adults, how much one wants to move with a piece of music (the amount of perceived groove) is related to how gait changes during music-based RAS, with high groove cues eliciting significantly greater stride velocity, stride length, and more accurate tempo matching (Leow et al., 2014; Leow et al., 2015). In some studies, gait also appears to be influenced by how familiar participants are with a stimulus (Leow et al., 2015).

During RAS, users are typically instructed to synchronize their footsteps with the beat of the music or metronome. It is hypothesized that these instructions are necessary for walkers to entrain their movement with the cues. Recent studies have reported that explicit instructions to synchronize are important for eliciting synchronization (Leow et al., 2018; Mendonça et al., 2014), as people do not tend to synchronize steps to the beat unless instructed to. However, synchronization instructions are not necessary to elicit changes in stride length or gait speed, and affect good and poor beat perceivers differently (Benoit et al., 2014; de Bruin et al., 2015). Instructions to synchronize may increase task difficulty for people with poor beat perception abilities (Leow et al., 2014; Leow et al., 2015; Ready et al., 2019), and performing difficult tasks while walking tends to reduce stride velocity and length. Importantly, larger strides and faster gait can be achieved among poor beat perceivers when using highly familiar

stimuli, perhaps by reducing the demand to predict beat onset (Leow et al., 2015). Therefore, the cognitive demands associated with RAS have potential to be reduced not only by removing instructions to synchronize but also by facilitating beat finding with familiar stimuli during cueing.

The effects on gait of differences in stimuli, instructions, and individual rhythmic ability are underexplored in the healthy older adult population. With the average age of PD diagnosis being 60 years (Inzelberg et al., 2002), older adults represent the demographic that is most often diagnosed with PD. Healthy older adults also experience general age-related gait and cognitive changes. Although these changes may be minor enough to have little functional impact on daily life, they may influence how older adults respond to a sensorimotor synchronization task. For example, older adults are more severely affected by dual-tasking while walking than younger adults, which suggests that the effect of auditory cues on gait could also differ between older and younger adults. Understanding how these factors impact older adults without Parkinson's is a valuable step in understanding the relationship between music and movement across the lifespan and for informing approaches to RAS in clinical populations.

Therefore, the purpose of this study was to explore how specific musical properties influence synchronized and free walking gait outcomes in healthy older adults with good and poor beat perception ability. To test this, participants were randomized to either free walking or synchronized instruction groups and walked to music that was high or low in familiarity and high or low in groove. Beat perception ability was assessed to examine how effects differed between good and poor beat perceivers. It was hypothesized that high groove cues would elicit faster and more stable gait with larger steps than low groove cues. Furthermore, poor beat perceivers were anticipated to demonstrate better gait outcomes when free walking instead of synchronizing, as any dual-task demands may have been reduced. In addition, poor beat perceivers were anticipated to demonstrate better gait outcomes for highly familiar compared to unfamiliar stimuli, as the familiarity may make it easier to extract and predict the beat, particularly when synchronizing.

4.1 Methods

4.1.1 Participants

50 healthy older adults were recruited from the community using study flyers and emails. Five participants were excluded due to missing data (one technological error, three due to difficulty understanding instructions, and one due to physical difficulty completing the gait study). Thus, analyses were conducted on 45 participants, all of whom self-reported being free of neurological or physical conditions impacting their gait or balance. All but four participants reported having normal or corrected to normal hearing. Two participants in each instruction group reported slight age-related hearing loss, and two participants in each group reported slight unilateral hearing loss. None reported difficulty perceiving the auditory stimuli during the experiment. Demographic data for participants is shown in Table 4.1. All participants provided informed, written consent as per the University of Western Ontario's Human Research Ethics Board (see Appendix G for Letter of Information). Participants were compensated for their time.

Table 4.1. Demographic data by subgroup.

	Free Walking		Synchronized Walking	
	Poor BP (n = 12)	Good BP (n = 11)	Poor BP (n = 12)	Good BP (n =10)
Age	66 (12)	61 (11)	61 (8)	59 (5)
Sex (Male/Female)	7/5	8/3	9/3	9/1
Years of music training	4.3 (5.2)	5.6 (7.6)	2.8 (4.9)	8.0 (5.7)
Years of dance training*	0.8 (1.4)	0.6 (1.6)	0.8 (2.0)	5.0 (5.2)

Note. Data presented as means (standard deviations) for age, music training, and dance training. Sums are presented for gender. BP = Beat Perceivers. *Seven participants reported having dance experience but did not report on the questionnaire how many years of training they had (4 free walkers, 3 synchronized walkers). Reported data for years of dance training exclude these participants.

4.1.2 Stimuli

Two stimulus databases were produced to accommodate varying levels of stimulus familiarity across the age group, as indicated by piloting. While a single database was sufficient for Study 1 with younger adults, age varied more across the current sample than in the younger adult sample, and piloting did not yield a single database that could produce reliable sets of familiar stimuli across ages 45-80+ years. Thus, participants under the age of 69 heard one database with 35 songs, and participants aged ≥ 70 years rated a different database of 33 songs. As in Study 1, stimuli in the database were alyrical versions of songs, and ratings were made based on representative 30-second clips. Ratings were completed for songs at the specific tempo that participants would be cued at (15% faster in beats per minute than natural cadence). Thus, they rated the actual stimuli that they subsequently walked to. Both stimulus lists are available in Appendix H.

4.1.3 Variations from General Gait Protocol

Participants in this study followed the same general protocol outlined in Chapter 2, however this group was provided with two cued practice trials, completed after the rating task and before the experimental cued walks. No data was recorded from practice walks. Practice trials were completed to account for the fact that this population may not be as accustomed to walking with music as younger adults that have been raised in an era of personal and portable listening devices (e.g., MP3 players, iPods, mobile phones).

All participants in this study completed practice trials to the same two stimuli: one low groove stimulus (My Heart Will Go On) and one high groove stimulus (Ol Country). Neither practice stimuli were used during the rating tasks or experimental gait trials. Free walking participants were instructed to practice walking with music in the background to familiarize with the task. Synchronized walkers were instructed to practice finding and matching footsteps to the beat.

4.1.4 Variation from General Demographic Assessment Protocol

Participants in this study completed an identical demographic questionnaire to the younger adults in Study 1 (Appendices A and B) with the following exception. This older adult sample answered additional questions regarding their synchronization performance at the end of the experiment (Appendix I). These questions were included not as part of the dissertation research question, but a separate research question regarding perceived synchronization ability, perception of which part of the gait cycle is matched to the beat, and perception of spontaneous synchronization among free walkers. These data are not included in the dissertation.

4.1.5 Data Analysis

As indicated in Chapter 2, initially, separate 4-way mixed design analyses of variance (ANOVAs) were conducted on each dependent variable using SPSS (version 22) with the following variables: familiarity (high, low), groove (high, low), instruction (synchronize, walk freely), and beat perception ability (poor, good). The following dependent variables were examined in separate ANOVA models. Family-wise Bonferroni adjustments were applied for the following families of DVs:

1. Spatial (step length, stride width)
2. Temporal (cadence, stride velocity, double-limb support time)
3. Variability (CV for step length, step time, stride velocity).

Thus, critical p values are as follows: 0.025 (spatial); 0.017 (temporal); and 0.017 (variability).

For most dependent variables, there were no significant or only marginally significant effects of familiarity or beat perception ability (all dependent variables but step length). Thus, analyses were collapsed across these factors, and 2x3 ANOVAs are reported in the results with the remaining factors instruction type (free walking, synchronized-walking) and stimulus (metronome, low groove, high groove) as independent variables. Greenhouse-Geisser corrections are reported where applicable. For completeness, original 4-way analyses including familiarity and beat perception ability are available in Appendix J.

To examine if RAS significantly altered any gait parameters from baseline (silent) walking, additional ANOVAs were run on the raw data instead of normalized change scores. Bonferonni-adjusted critical *p*-values, as reported above, were applied to these analyses to correct for multiple comparisons within families of dependent variables. For all dependent variables except step length 2 (instruction: free, synchronized) x 4 (cueing condition: baseline [no cue], low groove, high groove, metronome) ANOVAs were run. As step length analyses indicated interactions with familiarity and beat perception ability (as reported below), all original factors were retained in the analyses of raw data. Thus, a 3-way ANOVA with beat perception ability (good, poor), instruction type (free, synchronized), and cueing condition (baseline [no cue], high familiarity/high groove, high familiarity/low groove, low familiarity/high groove, low familiarity/low groove) was run. These data are available in Table 4.2.

4.2 Results

4.2.1 Spatial Gait Parameters

Step Length (cm).

Overall, steps appeared to shorten from baseline with auditory cues (Figure 4.1). There was a significant interaction between familiarity and beat perception ability [F (1, 41) = 6.4, p < .025, *np2* = .13] (Figure 4.1A). Follow-up t-tests indicated that poor beat perceivers shortened their strides significantly more when walking to low familiarity than high familiarity cues [t(23) = 3.08, p < .01]. Good beat perceivers demonstrated no differences between low and high familiarity cues [t(20) = -1.21, p > .05]. To examine the differences between stimulus types and metronome on gait, an additional one-way ANOVA with stimulus type (low familiarity/low groove, low familiarity/high groove, high familiarity/low groove, high familiarity/low groove, and metronome) was conducted. No significant effect of stimulus type was observed [F(1, 176) = 1.2, p > .05, *np2* = .03] suggesting no difference between metronome and other cueing conditions on step length.

Stride Width (cm).

Results from a 4-way ANOVA indicated no significant effects of familiarity, groove, beat perception ability, or instructions on stride width (Figure 4.1B). Thus, no effects were collapsed for a 2x3 ANOVA. Relevant statistics are available in Table 4.3.

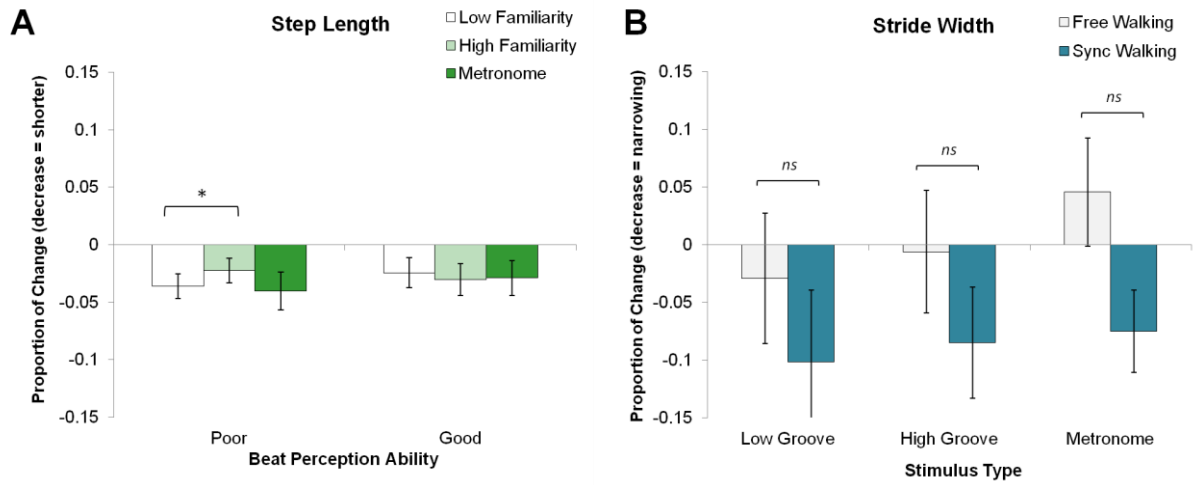


Figure 4.1. Mean normalized changes scores and standard error for spatial parameters. (A) step length and (B) stride width are shown between stimulus and instruction types. *Denotes significant interactions between stimulus and instruction types at p <.05. *ns* = non-significant.

4.2.2 Temporal Gait Parameters

Cadence (steps/minute).

A significant main effect of stimulus [F (1.5, 65.1) = 14.7, p < .001, $np2$ = .26] indicated that both high groove [M = 0.04, SD = 0.01] and metronome cues [M = 0.05, SD = 0.01] produced significantly faster cadence than low groove cues [M = -0.02, SD = 0.02]. In addition, a main effect of instruction [F (1, 43) = 8.5, p < .01, $np2$ = .16] was found, with synchronized walkers taking significantly more steps per minute [M = 0.04, SD = 0.01] than free walkers [M = -0.02, SD = 0.01]. See Figure 4.2A.

Stride Velocity (cm/sec).

A significant main effect of stimulus [F (1.9, 80.0) = 16.5, p < .001, $np2$ = .28] indicated that participants walked significantly faster to high groove [M = 0.01, SD = 0.02] and metronome cues [M = 0.01, SD = 0.02] than to low groove cues [M = -.05, SD = 0.02] (Figure 4.2B).

Double-Limb Support Time (seconds).

A significant main effect of stimulus was found [F (1.6, 67.6) = 7.1, p < .01, $np2$ = .14] (Figure 4.2C). Specifically, low groove cues [M = .05, SD .01] elicited significantly longer DLST than both high groove M = .02, SD = .08] and metronome [M = .02, SD = .08]. DLST did not differ between high groove and metronome cues.

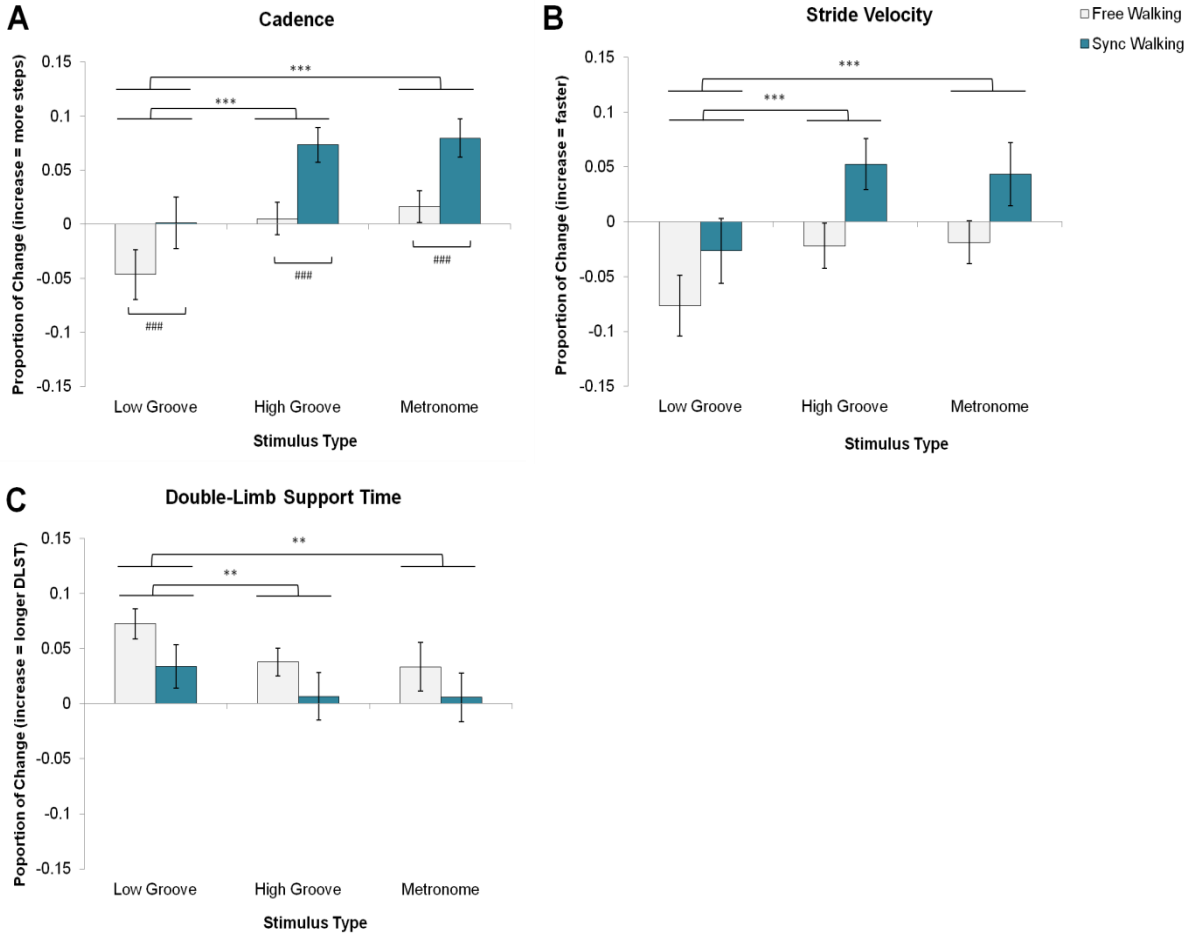


Figure 4.2. Mean normalized changes scores and standard error for temporal parameters. (A) Cadence, (B) stride velocity, and (C) double-limb support time are shown. ***Denotes significant main effects of stimulus type at p <.001. ** Denotes significance at p < .01. ### Denotes significant main effect of instruction type at p <.001.

Table 4.2. Raw means and standard deviations for stimulus and instruction conditions.

	Baseline	Low Groove	High Groove	Metronome
Step Length (cm)				
Free Walking	56.3 (7.9)	--	--	54.2 (8)*
Low Familiarity	--	54 (7.5)**	54.6 (8.2)*	--
High Familiarity	--	54.4 (7.1)**	54.7 (7.9)	--
Synchronized Walking	59.4 (4.2)	--	--	57.5 (7.5)
Low Familiarity	--	57.5 (6.1)	58.1 (5.7)	--
High Familiarity	--	57.7 (5.4)	58.3 (6)	--
Stride Width (cm)				
Free Walking	7.6 (2.6)	7.5 (3.1)	7.7 (3)	7.9 (2.8)
Synchronized Walking	7.1 (2.5)	6.3 (3.1)	6.5 (2.9)	6.5 (2.8)
Cadence (steps/min)				
Free Walking	109.4 (10)	104.7 (16.5)*	109.9 (11.6)	111 (10.8)
Synchronized Walking	112.4 (7.4)	112.3 (12.5)	120.6 (10.7)***	121.2 (11.3)***
Stride Velocity (cm/sec)				
Free Walking	103 (17.9)	94.9 (19.6)$^{\#}$	100.2 (17.8)	100.7 (17.8)
Synchronized Walking	111.2 (8.8)	108.5 (18.9)$^{\#}$	117.4 (17.2)	116.4 (19.1)
Double Limb Support Time (sec)				
Free Walking	13.5 (1.7)	14.5 (2.4)$^{\#\#}$	14 (1.8)	14 (1.7)
Synchronized Walking	13.4 (1.3)	13.8 (1.9)$^{\#\#}$	13.5 (1.9)	13.4 (2.1)
Step Length Variability (CV)				
Free Walking	4.7 (1.8)	4.8 (1.7)	5.1 (2)	5 (1.8)
Synchronized Walking	4.4 (1.6)	4.7 (1.3)	5.2 (1.6)	4.9 (2)
Step Time Variability (CV)				
Free Walking	3.5 (0.9)	4.3 (1.7)$^{\#\#\#}$	4.3 (2.2)$^{\#\#\#}$	3.8 (1.2)$^{\#}$
Synchronized Walking	3 (0.8)	4.2 (1.3)$^{\#\#\#}$	4.1 (1.6)$^{\#\#\#}$	3.3 (1.1)$^{\#}$
Stride Velocity Variability (CV)				
Free Walking	4.6 (1.5)	5 (1.9)	4.8 (1.7)	4.7 (1.4)
Synchronized Walking	3.9 (1.2)	4.7 (1.3)	4.4 (1.3)	4.1 (1.6)

Note. Raw values for all dependent variables averaged across beat perception ability. For all but step length, values are averaged across familiarity. Reported effects are significant at the family-wise corrected alpha levels reported in the study methods (Chapter 2).

*Denotes significant change from baseline within instruction groups (cueing condition interacted with instruction condition) at $p < .05$. ** $p < .01$. *** $p < .001$. $^{\#}$ Denotes significant change from baseline when averaged across instruction groups at $p < .05$ (stimulus type did not interact with instruction). $^{\#\#}$ $p < .01$. $^{\#\#\#}$ $p < .001$.

4.2.3 Variability Gait Parameters.

There were no significant effects of any factors on step length variability (Figure 4.3A), step time variability (Figure 4.3B), nor stride velocity variability (Figure 4.3C). See Table 4.3 for statistics.

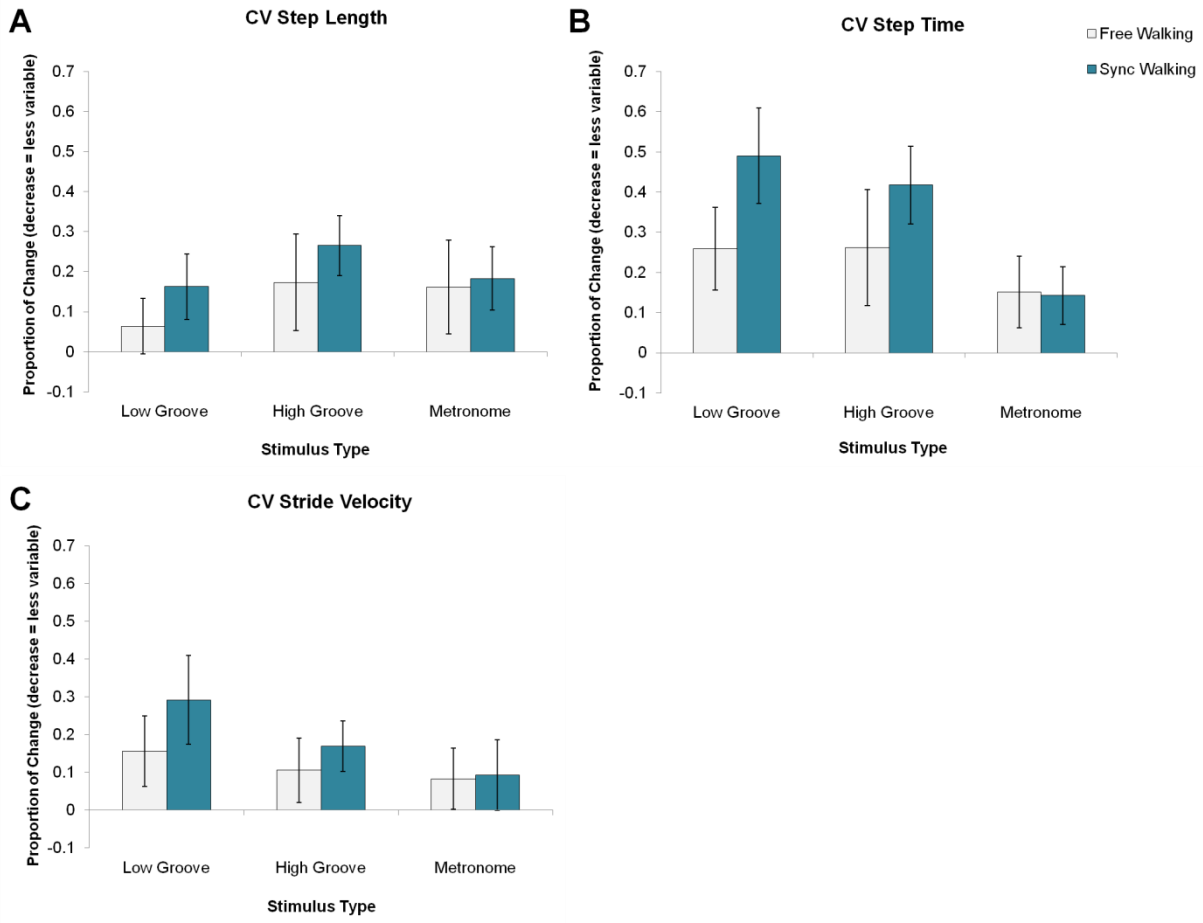


Figure 4.3 Mean normalized changes scores and standard error for variability measures. No effects for (A) CV step length, (B) CV step time, and (C) CV stride velocity reached significance.

Table 4.3. 4-way ANOVA results for variability.

	Stride Width (cm)			Step Length Variability (CV)			Step Time Variability (CV)			Stride Velocity Variability (CV)		
	F-Value	*p*-Value	*np2*	*F*-Value	*p*-Value	*np2*	*F*-Value	*p*-Value	*np2*	*F*-Value	*p* Value	*np2*
Familiarity	.265	.610	.006	3.010	.090	.068	2.910	.096	.066	1.830	.184	.043
Familiarity * Instruction	1.264	.267	.030	.287	.595	.007	.004	.951	.000	.563	.457	.014
Familiarity *BP	.724	.400	.017	3.270	.078	.074	1.503	.227	.035	.002	.966	.000
Familiarity*Instruction*BP	.029	.865	.001	3.224	.080	.073	5.667	.022	.121	1.991	.166	.046
Groove	.949	.336	.023	2.978	.092	.068	.384	.539	.009	3.183	.082	.072
Groove*Instruction	.049	.825	.001	.010	.922	.000	.415	.523	.010	.491	.488	.012
Groove*BP	.315	.578	.008	.002	.964	.000	.966	.331	.023	.231	.633	.006
Groove*Instruction*BP	.643	.427	.015	.337	.564	.008	.227	.636	.006	.518	.476	.012
Familiarity*Groove	.003	.955	.000	.009	.923	.000	.891	.351	.021	.372	.545	.009
Familiarity*Groove*Instruction	.466	.499	.011	5.405	.025	.116	.062	.804	.002	.142	.708	.003
Familiarity*Groove*BP	.001	.975	.000	.022	.884	.001	.191	.665	.005	1.130	.294	.027
Familiarity*Groove*Instruction*BP	.971	.330	.023	2.996	.091	.068	1.479	.231	.035	.820	.370	.020
Instruction	.993	.325	.024	.705	.406	.017	1.335	.255	.032	.540	.467	.013
BP	.014	.905	.000	1.781	.189	.042	.019	.890	.000	.564	.457	.014
Instruction*BP	.040	.842	.001	.450	.506	.011	3.236	.079	.073	3.282	.077	.074

Note. Bonferonni alpha adjustments were applied to adjust for multiple comparisons. Thus, the critical alpha value for stride width (a spatial gait parameter) is 0.025 and is 0.017 for all variability measures. BP = Beat Perception. *np2* = Partial eta squared (effect size).

4.3 Discussion

The aim of this study was to explore factors that influence gait during music-based auditory cueing in older adults. Specifically, this study examined how groove and familiarity impacted gait patterns among good and poor beat perceivers with and without instruction to synchronize to auditory cues that were 15% faster than preferred walking pace. Overall, healthy older adults shortened their steps when walking to the auditory cues. High groove and metronome cues increased gait speed with minimal change in DLST, while low groove cues slowed gait speed and increased DLST. As expected, synchronized walkers increased their cadence more than free walkers. Overall, there were no effects of cueing or instruction on stride width or gait variability.

4.3.1 High Groove Cues Improve Gait Outcomes

High groove cues were consistently associated with longer and faster steps than low groove cues. In this study, steps shortened across all cue types, but high groove and metronome cues elicited faster gait velocity and higher cadence (more steps per minute) than low groove cues. These findings are in line with those in younger adults (Leow et al., 2014; Leow et al., 2015; Ready et al., 2019) and suggest that groove contributes to faster speed during musically-cued walking in both healthy younger and older adults.

Low groove cues did not worsen stability-related measurements (e.g., stride width, step-to-step variability). Studies in healthy younger adults have not reported negative effects of groove on gait stability. However, there are reasons to predict low groove could worsen gait in older adults. Older adults generally have a wider gait stance, more postural sway, and higher gait variability during normal walking than do younger adults (Aboutorabi et al., 2016; Laughton et al., 2003). Furthermore, older adults are more prone to deterioration in these parameters when faced with challenging gait situations such as dual-tasking (Maylor & Wing, 1996; Priest, Salamon, & Hollman, 2008) or obstacle avoidance (Caetano et al., 2016; Kovacs, 2005). These factors could put them at a greater risk of experiencing stability related detriments that young adults may not with low groove cueing; however, this was not the case, suggesting that low groove cues do not compromise gait stability in older adults.

4.3.2 Instructions to Synchronize Impact Gait

In this study, synchronized walkers had higher cadence during cueing than did free walkers. Thus, instructions to synchronize may successfully enhance the positive effects of auditory cues (such as faster gait) without eliciting negative effects, such as increased variability or decreased stability. Previous studies have found that participants who synchronize to auditory cues demonstrate significantly shorter and slower strides to low groove cues than participants who are not instructed to synchronize (Ready et al., 2019). In contrast, here, synchronized walkers increased cadence more than free walkers, regardless of cue type. This suggests that synchronizing to low groove cues did not worsen the effects of low groove cues on gait, unlike younger adults who demonstrate less accurate tempo matching to low groove cues (Ready et al., 2019). The finding that synchronized walkers adapted their tempo more than free walkers across all conditions supports previous reports that spontaneous synchronization does not occur without explicit instructions to do so (Leow et al., 2018; Ready et al., 2019). However, it should still be noted that low groove cues elicited lower cadence than high groove and metronome cues and, therefore, do not achieve the same outcome. An interesting observation is that synchronized walkers do not appear to have truly tempo matched, despite adjusted their cadence more than free-walkers. In other words, they did not adjust cadence by a full 15%. This lack of tempo matching may suggest that the accelerated cue rate was difficult for participants to achieve.

4.3.3 Beat perception Ability and Familiarity

Beat perception ability and familiarity may be factors that interact to impact gait outcomes to music-based RAS. Leow et al. (2015) found that poor beat perceivers showed faster and less variable gait when synchronizing to familiar than unfamiliar stimuli. Ready et al. (2019) did not find an interaction between familiarity and beat perception ability, but found that poor beat perceivers had better balance-related gait parameters when walking freely instead of synchronizing. Both of these studies suggest that people with less accurate beat perception ability may respond differently to auditory cues than people with strong beat perception abilities, particularly when synchronizing. This may be related to difficulty with beat finding and, consequently, the ability to adjust body movements to be in time with the beat.

In this study, poor beat perceivers shortened their strides more than good beat perceivers when walking to unfamiliar stimuli. Shortening of strides is commonly observed among older adults when dual-tasking (Lee, 2017). Therefore, finding this only for poor beat perceivers with unfamiliar cues could suggest sensorimotor synchronization was more difficult in this condition. Importantly, this effect did not appear to be related specifically to the instructions to synchronize. Leow et al. (2015) suggest that greater familiarity with a stimulus reduces the demand required to accurately predict beat onsets, thus reducing the cognitive demands of synchronizing, and limiting gait deteriorations such as increased gait variability or slowing and shortening of strides. In the present study, there were no effects of beat perception ability on cadence, which suggests that poor beat perceivers were not necessarily any less able to adjust their cadence to match the beat but that, perhaps, the shortening of steps reflects the increased cognitive demand among poor beat perceivers in this condition.

4.3.4 Music versus Metronome Cues

The aim of this study was not specifically to assess if musical cues were more or less beneficial than metronome cues; however, metronome cues are an interesting control stimulus for perceived groove levels as they have strong beat salience but are not typically associated with any desire to move. There is no clear consensus in the literature indicating whether metronome or music cues are better for achieving gait changes, and few studies have accounted for groove when comparing music and metronome cues. In previous research, low groove cues produced slower and shorter strides than metronome cues (Leow et al., 2015; Ready et al., 2019). Generally, high groove music and metronome cues have produced similar outcomes to one another (Leow et al., 2014; Leow et al., 2015). However, Ready et al. (2019) found that high groove cues produced longer and faster strides than metronome cues when cueing younger adults at their self-selected walking pace. The current study is one of the first to compare high and low groove music stimuli with metronome cues during RAS among healthy older adults rather than younger adults. High groove and metronome cues elicited increases in gait speed when cueing at an accelerated rate, similar to younger adults cued at walking pace, but low groove cues elicited unfavourable gait changes (slowing and increased DLST). Thus, high groove and metronome cues have the potential be used interchangeably whereas low groove cues do not. An interesting future line of research would be to explore the

effects of combining high groove music with metronome cues to further enhance beat salience.

4.3.5 Acceleration of Cues Relative to Natural Walking Pace

The findings of temporal changes, but not step length changes, support previous work that accelerated auditory cues may affect gait speed but not step length. This is consistent with observations in other healthy younger adult studies and clinical RAS studies that suggest cueing at faster pace does not globally improve gait. It is important to note which gait parameters are altered by auditory cues when the ultimate goal is to target specific symptoms in a clinical population. Parkinsonian gait manifests with a slow walking pattern that is characterized, in part, by decreased step length. If cues only improve gait speed by increasing cadence, but not step length (or even decreasing step length) then cues may not, in fact, be appropriate for people experiencing symptomatic reduction in step length. Instead, the effects of various cue properties need to be further explored to understand how to best optimize step length while increasing gait velocity.

As previously indicated, cadence adjustments observed in this study did not approximate the 15% increase that would be expected if participants accurately tempo-matched with cues that were 15% faster than baseline walking rate. On average, synchronized walkers increased cadence by approximately seven to eight per cent with metronome and high groove cues. In contrast, free walkers increased their cadence by an average of less than two per cent for metronome and high groove cues. This further supports previous work that participants generally do not synchronize to auditory cues unless explicitly instructed. Moreover, this is an important finding to consider when determining an appropriate cue pace for RAS. If the aim is to foster sensorimotor synchronization but participants a) do not achieve this, and b) demonstrate potential reductions in balance-related gait parameters, it may suggest that undesirable RAS outcomes are achieved when cues are too fast. The aim of this study was not to determine the most optimal cue pace; however, these findings highlight the importance of addressing the cue-pace question in future RAS studies.

4.4 Conclusions

In summary, auditory cues that are 15% faster than natural walking rate can increase gait speed in healthy older adults, but this may come at the cost of step length in some cases. As expected, gait speed was consistently faster for high groove and metronome cues than for low groove cues. Synchronizing appeared to enhance gait cadence, which may suggest entrainment; however, low groove cues were not associated with the same increase in cadence elicited with high groove an metronome cues. Poor beat perceivers demonstrated a potentially cautious approach to walking by shortening steps while walking to unfamiliar stimuli, which may support that unfamiliar stimuli can negatively impact RAS outcomes. Importantly, the finding that step shortening was not associated with the instruction to synchronize may indicate that shortening is not solely related to the task of synchronizing. Overall, these results support that high groove music and metronome cues produce better gait outcomes than low groove cues, but highlight the need to further explore what instructions and cue paces are most appropriate for music-based auditory cueing in older adults and clinical populations.

References

Aboutorabi, Arazpour, Bahramizadeh, Hutchins, & Fadayevatan. (2016). The effect of aging on gait parameters in able-bodied older subjects: a literature review. *Aging Clinical and Experimental Research, 28*(3), 393-405. doi:10.1007/s40520-015-0420-6

Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn. (2011). Cognitive motor interference while walking: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews, 35*(3), 715-728. doi:10.1016/j.neubiorev.2010.08.008

Amboni, Barone, & Hausdorff. (2013). Cognitive contributions to gait and falls: evidence and implications. *Movement disorders : official journal of the Movement Disorder Society, 28*(11), 1520-1533. doi:10.1002/mds.25674

Balash, Peretz, Leibovich, Herman, Hausdorff, & Giladi. (2005). Falls in outpatients with Parkinson's disease. *Journal of Neurology, 252*(11), 1310-1315. doi:10.1007/s00415-005-0855-3

Benoit, Dalla Bella, Farrugia, Obrig, Mainka, & Kotz. (2014a). Musically cued gait-training improves both perceptual and motor timing in Parkinson's disease. *Front Hum Neurosci, 8*, 494. doi:10.3389/fnhum.2014.00494

Blin, Ferrandez, & Serratrice. (1990). Quantitative analysis of gait in Parkinson patients: increased variability of stride length. *J Neurol Sci, 98*(1), 91-97.

Bugalho, Alves, & Miguel. (2013). Gait dysfunction in Parkinson's disease and normal pressure hydrocephalus: a comparative study. *Journal of Neural Transmission, 120*(8), 1201-1207. doi:10.1007/s00702-013-0975-3

Caetano, Lord, Schoene, Pelicioni, Sturnieks, & Menant. (2016). Age-related changes in gait adaptability in response to unpredictable obstacles and stepping targets. *Gait & Posture, 46*, 35-41. doi:https://doi.org/10.1016/j.gaitpost.2016.02.003

Callisaya, Beare, Phan, Blizzard, Thrift, Chen, & Srikanth. (2013). Brain structural change and gait decline: a longitudinal population-based study. *J Am Geriatr Soc, 61*(7), 1074-1079. doi:10.1111/jgs.12331

Cameron, Bentley, & Grahn. (2015). Cross-cultural influences on rhythm processing: reproduction, discrimination, and beat tapping. *Frontiers in psychology, 6*(366). doi:10.3389/fpsyg.2015.00366

Cameron, Stewart, Pearce, Grube, & Muggleton. (2012). Modulation of Motor Excitability by Metricality of Tone Sequences. *Psychomusicology: Music, Mind, and Brain, 22*(2), 122-128. doi:10.1037/a0031229

Canadian Institute for Health Information. (2007). *The Burden of Neurological Diseases, Disorders and Injuries in Canada* Ottawa: CIHI.

Chen, Penhune, & Zatorre. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cereb Cortex, 18*(12), 2844-2854. doi:10.1093/cercor/bhn042

Dalla Bella, Benoit, Farrugia, Keller, Obrig, Mainka, & Kotz. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Sci Rep, 7*, 42005. doi:10.1038/srep42005

Dalla Bella, Dotov, Bardy, & Cock Valérie. (2018). Individualization of music-based rhythmic auditory cueing in Parkinson's disease. *Annals of the New York Academy of Sciences, 0*(0). doi:10.1111/nyas.13859

Dalla Bella, Sowi, & ski. (2015). Uncovering Beat Deafness: Detecting Rhythm Disorders with Synchronized Finger Tapping and Perceptual Timing Tasks. *Journal of Visualized Experiments*(97), e51761. doi:doi:10.3791/51761

de Bruin, Kempster, Doucette, Doan, Hu, & Brown. (2015). The effects of music salience on the gait performance of young adults. *Journal of Music Therapy, 52*(3), 394-419. doi:10.1093/jmt/thv009

de Lau, & Breteler. (2006). Epidemiology of Parkinson's disease. *Lancet Neurology, 5*(6), 525-535. doi:10.1016/S1474-4422(06)70471-9

DeLong. (1990). Primate models of movement disorders of basal ganglia origin. *Trends in Neurosciences, 13*(7), 281-285.

Ebersbach, Moreau, Gandor, Defebvre, & Devos. (2013). Clinical syndromes: Parkinsonian gait. *Movement Disorders, 28*(11), 1552-1559. doi:10.1002/mds.25675

Fahn. (1999). Parkinson disease, the effect of levodopa, and the elldopa trial. *Archives of Neurology, 56*(5), 529-535. doi:10.1001/archneur.56.5.529

Fahn, Oakes, Shoulson, Kieburtz, Rudolph, Lang, . . . Parkinson Study. (2004). Levodopa and the Progression of Parkinson's Disease. *The New England Journal of Medicine, 351*(24), 2498-2508.

Farrer. (2006). Genetics of Parkinson disease: paradigm shifts and future prospects. *Nature Reviews. Genetics, 7*(4), 306-318. doi:http://dx.doi.org/10.1038/nrg1831

Ghai, Ghai, & Effenberg. (2018a). Effect of Rhythmic Auditory Cueing on Aging Gait: A Systematic Review and Meta-Analysis. *Aging and disease, 9*(5), 901-923. doi:10.14336/AD.2017.1031

Ghai, Ghai, Schmitz, & Effenberg. (2018b). Effect of rhythmic auditory cueing on parkinsonian gait: A systematic review and meta-analysis. *Sci Rep, 8*(1), 506. doi:10.1038/s41598-017-16232-5

Grahn, & Brett. (2009). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex, 45*(1), 54-61. doi:10.1016/j.cortex.2008.01.005

Grahn, & Rowe. (2009). Feeling the beat: premotor and striatal interactions in musicians and nonmusicians during beat perception. *J Neurosci, 29*(23), 7540-7548. doi:10.1523/jneurosci.2018-08.2009

Grahn, & Schuit. (2012). Individual Differences in Rhythmic Ability: Behavioral and Neuroimaging Investigations. *Psychomusicology, 22*(2), 105-121. doi:10.1016/ S1364-6613(00)01538-2

Gupta. (2002). Anatomy and physiology of the Basal Ganglia. *Psychiatric Annals, 32*(4), 230-232.

Hausdorff, Cudkowicz, Firtion, Wei, & Goldberger. (1998a). Gait variability and basal ganglia disorders: stride-to-stride variations of gait cycle timing in Parkinson's disease and Huntington's disease. *Mov Disord, 13*. doi:10.1002/mds.870130310

Hausdorff, Cudkowicz, Firtion, Wei, & Goldberger. (1998b). Gait variability and basal ganglia disorders: Stride-to-stride variations of gait cycle timing in parkinson's disease and Huntington's disease. *Movement Disorders, 13*(3), 428-437. doi:10.1002/mds.870130310

Health Canada, & Parkinson Society Canada. (2003). *Parkinson's Disease: Social and Economic Impact*. Toronto: PSC.

Hollman, Childs, McNeil, Mueller, Quilter, & Youdas. (2010). Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. *Gait & Posture, 32*(1), 23-28. doi:https://doi.org/10.1016/j.gaitpost.2010.02.017

Honma, Kuroda, Futamura, Shiromaru, & Kawamura. (2016). Dysfunctional counting of mental time in Parkinson's disease. *Sci Rep, 6*, 25421. doi:10.1038/srep25421

https://www.nature.com/articles/srep25421#supplementary-information

Hung, & Schwarzschild. (2014). Treatment of Parkinson's Disease: What's in the Non-dopaminergic Pipeline? *Neurotherapeutics, 11*(1), 34-46. doi:10.1007/s13311-013-0239-9

Inzelberg, Schechtman, & Paleacu. (2002). Onset age of Parkinson disease. *American Journal of Medical Genetics, 111*(4), 459-460. doi:10.1002/ajmg.10586

Janata, Tomic, & Haberman. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General, 141*(1), 54-75. doi:http://dx.doi.org/10.1037/a0024208

Jankovic. (2008). Parkinson's disease: clinical features and diagnosis. *Journal of Neurology, Neurosurgery & Psychiatry, 79*(4), 368-376. doi:10.1136/jnnp.2007.131045

Kim, Allen, Canning, & Fung. (2013). Postural Instability in Patients with Parkinson's Disease: Epidemiology, Pathophysiology and Management. *CNS Drugs, 27*(2), 97-112. doi:10.1007/s40263-012-0012-3

Kovacs. (2005). Age-Related Changes in Gait and Obstacle Avoidance Capabilities in Older Adults: A Review. *Journal of Applied Gerontology, 24*(1), 21-34. doi:10.1177/0733464804271279

Kung, Chen, Zatorre, & Penhune. (2013). Interacting cortical and basal ganglia networks underlying finding and tapping to the musical beat. *J Cogn Neurosci, 25*(3), 401-420. doi:10.1162/jocn_a_00325

Laughton, Slavin, Katdare, Nolan, Bean, Kerrigan, . . . Collins. (2003). Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait & Posture, 18*(2), 101-108. doi:https://doi.org/10.1016/S0966-6362(02)00200-X

Launay, Grube, & Stewart. (2014). Dysrhythmia: a specific congenital rhythm perception deficit. *Front Psychol, 5*, 18. doi:10.3389/fpsyg.2014.00018

Lee. (2017). Effects of single and dual tasks during walking on spatiotemporal gait parameters of community-dwelling older. *Journal of Physical Therapy Science, 29*(10), 1874-1877. doi:10.1589/jpts.29.1874

Leow, Parrott, & Grahn. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Leow, Rinchon, & Grahn. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *Annals of the New York Academy of Sciences, 1337*(1), 53-61. doi:10.1111/nyas.12658

Leow, Waclawik, & Grahn. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research, 236*(1), 99-115. doi:10.1007/s00221-017-5110-5

Lim, van Wegen, de Goede, Deutekom, Nieuwboer, Willems, . . . Kwakkel. (2005). Effects of external rhythmical cueing on gait in patients with Parkinson's disease: a systematic review. *Clinical Rehabilitation, 19*(7), 695-713. doi:10.1191/0269215505cr906oa

Limousin, & Martinez-Torres. (2008). Deep brain stimulation for Parkinson's disease. *Neurotherapeutics, 5*(2), 309-319. doi:10.1016/j.nurt.2008.01.006

Macphee, & Stewart. (2012). Parkinson's disease – pathology, aetiology and diagnosis. *Reviews in Clinical Gerontology, 22*(3), 165-178. doi:10.1017/S095925981200007X

Maylor, & Wing. (1996). Age differences in postural stability are increased by additional cognitive demands. *J Gerontol B Psychol Sci Soc Sci, 51*. doi:10.1093/geronb/51B.3.P143

Mazzoni, Hristova, & Krakauer. (2007). Why Don't We Move Faster? Parkinson's Disease, Movement Vigor, and Implicit Motivation. *The Journal of Neuroscience, 27*(27), 7105. doi:10.1523/JNEUROSCI.0264-07.2007

McAuley, Daly, & Curtis. (2009). A preliminary investigation of a novel design of visual cue glasses that aid gait in Parkinson's disease. *Clinical Rehabilitation, 23*(8), 687-695. doi:10.1177/0269215509104170

Mendonça, Oliveira, Fontes, & Santos. (2014). The effect of instruction to synchronize over step frequency while walking with auditory cues on a treadmill. *Hum Mov Sci, 33*, 33-42. doi:10.1016/j.humov.2013.11.006

Moore, Peretz, & Giladi. (2007). Freezing of gait affects quality of life of peoples with Parkinson's disease beyond its relationships with mobility and gait. *Movement Disorders, 22*(15), 2192-2195. doi:10.1002/mds.21659

Niv, Joel, & Dayan. (2006). A normative perspective on motivation. *Trends in Cognitive Sciences, 10*(8), 375-381. doi:10.1016/j.tics.2006.06.010

O'Shea, Morris, & Iansek. (2002). Dual task interference during gait in people with Parkinson disease: Effects of motor versus cognitive secondary tasks. *Physical Therapy, 82*(9), 888-897.

Pastor, Artieda, Jahanshahi, & Obeso. (1992). Time estimation and reproduction is abnormal in Parkinson's disease. *Brain, 115 Pt 1*, 211-225.

Patel, Jankovic, & Hallett. (2014). Sensory aspects of movement disorders. *Lancet Neurology, 13*(1), 100-112. doi:10.1016/S1474-4422(13)70213-8

Perry, Carville, Smith, Rutherford, & Newham. (2007). Strength, power output and symmetry of leg muscles: effect of age and history of falling. *European Journal of Applied Physiology, 100*(5), 553-561. doi:10.1007/s00421-006-0247-0

Phillips-Silver, Toiviainen, Gosselin, Piché, Nozaradan, Palmer, & Peretz. (2011). Born to dance but beat deaf: A new form of congenital amusia. *Neuropsychologia, 49*(5), 961-969. doi:10.1016/j.neuropsychologia.2011.02.002

Priest, Salamon, & Hollman. (2008). Age-related differences in dual task walking: a cross sectional study. *Journal of NeuroEngineering and Rehabilitation, 5*(1), 29. doi:10.1186/1743-0003-5-29

Qualtrics. (2018). Provo, Utah, USA. Retrieved from https://www.qualtrics.com

Ready, McGarry, Rinchon, Holmes, & Grahn. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait & Posture, 68*, 555-561. doi:https://doi.org/10.1016/j.gaitpost.2018.12.038

Rennie, Löfgren, Moe-Nilssen, Opheim, Dietrichs, & Franzén. (2018). The reliability of gait variability measures for individuals with Parkinson's disease and healthy older adults – The effect of gait speed. *Gait & Posture, 62*, 505-509. doi:https://doi.org/10.1016/j.gaitpost.2018.04.011

Roberts. (2017). *Comparing the influence of music enjoyment and beat perception ability on spatiotemporal gait parameters among healthy young and older adults.* (Master of Science), University of Western Ontario, Electronic Thesis and Dissertation Repository. Retrieved from https://ir.lib.uwo.ca/etd/4893 (4893)

Rocha, Porfírio, Ferraz, & Trevisani. (2014). Effects of external cues on gait parameters of Parkinson's disease patients: A systematic review. *Clinical Neurology and Neurosurgery, 124*, 127-134. doi:10.1016/j.clineuro.2014.06.026

Ruiz, Catalán, & Carril. (2011). Initial Motor Symptoms of Parkinson Disease. *The Neurologist, 17*, S18-S20. doi:10.1097/NRL.0b013e31823966b4

Schapira. (2009). Neurobiology and treatment of Parkinson's disease. *Trends in Pharmacological Sciences, 30*(1), 41-47. doi:10.1016/j.tips.2008.10.005

Sethi. (2008). Levodopa unresponsive symptoms in Parkinson disease. *Movement Disorders, 23*(S3), S521-S533. doi:10.1002/mds.22049

Shulman, De Jager, & Feany. (2011). Parkinson's Disease: Genetics and Pathogenesis. *Annual Review of Pathology: Mechanisms of Disease, 6*, 193-222. doi:10.1146/annurev-pathol-011110-130242

Smith, Harper, Gittings, & Abernethy. (2007). The effect of Parkinson's disease on time estimation as a function of stimulus duration range and modality. *Brain Cogn, 64*(2), 130-143. doi:10.1016/j.bandc.2007.01.005

Sofuwa, Nieuwboer, Desloovere, Willems, Chavret, & Jonkers. (2005). Quantitative Gait Analysis in Parkinson's Disease: Comparison With a Healthy Control Group. *Archives of Physical Medicine and Rehabilitation, 86*(5), 1007-1013. doi:10.1016/j.apmr.2004.08.012

Spaulding, Barber, Colby, Cormack, Mick, & Jenkins. (2013). Cueing and Gait Improvement Among People With Parkinson's Disease: A Meta-Analysis. *Archives of Physical Medicine and Rehabilitation, 94*(3), 562-570. doi:10.1016/j.apmr.2012.10.026

Stupacher, Hove, & Janata. (2016). Audio Features Underlying Perceived Groove and Sensorimotor Synchronization in Music. *Music Perception: An Interdisciplinary Journal, 33*(5), 571. doi:10.1525/mp.2016.33.5.571

Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller. (2013). Musical groove modulates motor cortex excitability: A TMS investigation. *Brain and Cognition, 82*(2), 127-136. doi:https://doi.org/10.1016/j.bandc.2013.03.003

Švehlík, Zwick, Steinwender, Linhart, Schwingenschuh, Katschnig, . . . Enzinger. (2009). Gait Analysis in Patients With Parkinson's Disease Off Dopaminergic Therapy. *Archives of*

Physical Medicine and Rehabilitation, 90(11), 1880-1886. doi:10.1016/j.apmr.2009.06.017

Wall, De La Parra, Callaway, & Kreitzer. (2013). Differential Innervation of Direct- and Indirect-Pathway Striatal Projection Neurons. *Neuron, 79*(2), 347-360. doi:10.1016/j.neuron.2013.05.014

Widnell. (2005). Pathophysiology of motor fluctuations in Parkinson's disease. *Movement Disorders, 20*(S11), S17-S22. doi:10.1002/mds.20459

Wielinski, Erickson-Davis, Wichmann, Walde-Douglas, & Parashos. (2005). Falls and injuries resulting from falls among patients with Parkinson's disease and other parkinsonian syndromes. *Movement Disorders, 20*(4), 410-415. doi:10.1002/mds.20347

Wittwer, Webster, & Hill. (2013). Music and metronome cues produce different effects on gait spatiotemporal measures but not gait variability in healthy older adults. *Gait Posture, 37*(2), 219-222. doi:10.1016/j.gaitpost.2012.07.006

Yelnik. (2002). Functional anatomy of the basal ganglia. *Movement Disorders, 17*(S3), S15-S21. doi:10.1002/mds.10138

Yogev, Giladi, Peretz, Springer, Simon, & Hausdorff. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: which aspects of gait are attention demanding? *Eur J Neurosci, 22*. doi:10.1111/j.1460-9568.2005.04298.x

Zatorre. (2015). Musical pleasure and reward: mechanisms and dysfunction. *Ann N Y Acad Sci, 1337*, 202-211. doi:10.1111/nyas.12677

Zhu, Li, Ye, Jiang, Lei, & Shu. (2016). Sensory symptoms in Parkinson's disease: Clinical features, pathophysiology, and treatment. *Journal of Neuroscience Research, 94*(8), 685-692. doi:10.1002/jnr.23729

Chapter 5

5 Accelerated Music-Based RAS in Parkinson's Disease

Gait impairments in Parkinson's disease are characterized by slowing and shortening of strides with increased step-to-step variability (Bugalho et al., 2013; Ebersbach et al., 2013; Hausdorff et al., 1998; Švehlík et al., 2009). These gait changes put people with PD at a higher fall risk (Schaafsma et al., 2003) and significantly impact how they engage in the world around them. People with PD who experience significant mobility impairment report decreased quality of life, feelings of isolation, and fear of falling during activity engagement (Marr, 1991; Schrag et al., 2000; Soundy et al., 2013). Unfortunately, gait impairments are difficult to manage with medication on a long-term basis (Fahn, 1999; Hung & Schwarzschild, 2014). Thus, allied health professionals, such as occupational and physical therapists, require rehabilitative strategies to foster safe and functional mobility (Deane, Ellis-Hill, Dekker, Davies, & Clarke, 2003; Tomlinson et al., 2012).

Rhythmic auditory stimulation (RAS) is ubiquitously recommended to regulate gait in PD (Aragon & Kings, 2018; Keus et al., 2007; Sturkenboom et al., 2008). However, little detail is provided in clinical guidelines for how to appropriately implement auditory cues. Most guidelines suggest using metronome cues but typically lack specific instructions about how to best implement RAS (e.g., how to appropriately select cue pace, or how to account for individual differences). Recent RAS literature has highlighted that auditory cueing may not be as straight forward as providing a metronome uniformly across all people to achieve the same outcome (Dalla Bella et al., 2017; Dalla Bella et al., 2018; Ghai, Ghai, Schmitz & Effenberg, 2018; Leow et al., 2014). The previous two studies in this dissertation, along with the cited literature, highlight the importance of carefully considering the type of auditory cue provided and how instructional demands alter the efficacy of the intervention.

Despite a growing body of literature on how specific musical properties (groove, familiarity) or individual abilities (beat perception ability, synchronization ability) influence RAS outcomes in healthy adults (de Bruin et al., 2010; Leow et al., 2014; Leow et al., 2015; Leow et al., 2018; Ready et al., 2019), only a handful of studies have investigated how such factors influence auditory cueing in clinical populations (Dalla Bella et al., 2017; Dalla Bella et al.,

2018; Patterson, Wong, Knorr, & Grahn, 2018). PD significantly impacts parts of the brain that are crucial for a various aspects of music processing (Cameron et al., 2016; Grahn & Brett, 2009). Therefore, it is unknown if factors such as perceived groove or beat perception ability will have a similar impact on people with PD as those without.

This study aimed to elucidate how stimulus familiarity, groove, and instructions to synchronize impact people with PD with good and poor beat perception ability during an accelerated, music-based RAS paradigm. To do this, people with PD were randomized to instruction conditions (synchronize with the beat or walk freely) before walking to music that ranged in familiarity (high, low) and perceived groove (high, low) and was 10% faster than their baseline walking rate. Beat perception ability was assessed to determine how effects differed between good and poor beat perceivers. Given the challenges associated with dual-tasking in PD, it was predicted that poor beat perceivers would demonstrate negative effects on gait (e.g., wider strides, longer DLST, higher variability) when synchronizing, in particular to music that was unfamiliar and required more attention for beat finding. Music perceived to be high in groove was hypothesized to elicit faster gait, higher cadence, and larger steps compared to music perceived as low groove.

5.1 Methods

5.1.1 Participants

23 volunteers diagnosed with idiopathic Parkinson's disease were recruited from the community in Southwestern Ontario using community outreach and study flyers. Only participants who could walk independently (i.e., without the aid of a person or mobility device), who do not experience regular freezing of gait, and who had been on a stable level of medication for over four weeks were eligible for the study. Given the exploratory nature of this study, participants were not excluded on the basis of medication regimen (e.g., not taking medication), years since diagnosis, or previously having deep brain stimulation. Thus, one participant with deep-brain stimulation and one not taking medication were included in the experiment.

Two participants were excluded from analyses: one due to technical error and one due to difficulty completing the full experiment (due to cognition). Thus, the final sample reported in the analyses consists of 21 participants. All participants provided their informed, written consent as per the University of Western Ontario's Human Research Ethics Board (Appendix K) and received monetary compensation for their time.

5.1.2 Stimuli

Stimuli in this study came from the same database that was used for Study 2 (Chapter 4). However, the database was revised to reduce the length of the rating task to accommodate the constraints of testing participants during peak-on phase of their medication cycle. To do this, only the 20 songs most consistently placed in the four conditions in the previous study were rated by the participants in this study (Appendix L). The same custom MATLAB script was used to select two stimuli whose ratings best matched the four musical cueing conditions: high familiarity/high groove, high familiarity/low groove, low familiarity/high groove, low familiarity low groove. In addition, participants completed two cued walks with metronome stimuli, as in the previous study.

The findings from the previous two studies in this dissertation were that cues at 15% faster than preferred rate shortened steps, therefore participants in this study were instead cued at 10% faster than their baseline walking rate. Thus, all stimuli were heard at +10% for both the rating task and for cued gait trials.

5.1.3 Procedures

Testing occurred during each participant's self-reported peak "ON" phase of their medication cycle (approximately 45 minutes to one hour after taking medication). This study followed the same general protocol for baseline gait measurement, stimulus ratings, cued walking, and the Beat Alignment Test as in the previous studies in this dissertation (described in Chapter 2). Baseline gait data was acquired prior to hearing any music and from eight consecutive passes of the pressure sensor walkway. Following this, participants completed the rating task with all stimuli to indicate their familiarity and perception of groove with each potential stimulus. Two practice trials (with the procedures reported in Chapter 4) were completed, followed by eight

cued walking trials. Trials were completed in a randomized order to two stimuli for each of the following four conditions based on ratings: high familiarity/high groove, high familiarity/low groove, low familiarity/high groove, low familiarity/low groove. Testing was completed during the self-reported peak "ON" phase of each participant's medication cycle. Lastly, participants completed the Beat Alignment Test for measurement of beat perception ability.

5.1.4 Clinical Examination

A series of clinical assessments were also completed. To assess motor symptom severity and disease stage, the motor examination subsection of the Movement Disorder Society Unified Parkinson's Disease Rating Scale (MDS-UPDRS III; Goetz et al., 2007) and the Timed Up-And-Go (TUG; Podsiadlo & Richardson, 1991) test were completed. These assessments were completed at the outset of the study, immediately prior to the experiment, to ensure they were completed in the peak-on phase of each participant's medication cycle along with the experimental trials. Examination was performed by the author, a registered occupational therapist with certification from the Movement Disorder Society for assessment and scoring of the MDS-UPDRS. Clinical guidance on administration and scoring of this assessment was provided to the author by Dr. Mary Jenkins (MD), a neurological movement disorder specialist, prior to beginning the study.

To assess mental state for demographic purposes, participants also completed the Montreal Cognitive Assessment version 7.2 (MoCA; Nasreddine et al., 2005), the Beck Depression Inventory (BDI; Beck, Ward, Mendolson, Mock, & Erbaugh, 1961) , the Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988)), and the Starkstein Apathy Scale (SAS; Starkstein et al., 1992). These tests were completed after the Beat Alignment Test to ensure that all experimental data was captured during the on-phase of each participant's medication cycle. These data are provided in table 5.1.

5.1.5 Demographic Assessment

Participants completed the same demographic questionnaire as the older adults in Study 2 (Chapter 4; Appendices A, B, H); however, the musical training background section was

removed and replaced with the Musical Training subscale of the Goldsmith Musical Sophistication Index (GMSI) (Mullensiefen, Gingras, Musil, & Stewart, 2014). The GMSI provides a standardized score that represents musical training/ability based on normative data in the general Western population. While this involved an additional change from the older adult protocol, this was done to support a separate collaborative project not included in this thesis, and the GMSI includes the same information as the musical training questionnaire. For reference, the Musical Training subscale is available in Appendix M.

5.1.6 Data Analysis

As in the other studies, 4-way ANOVAs were run initially with familiarity (high, low) and groove (high, low) as within-subject variables and beat perception ability (good, poor) and instruction type (free walking, synchronized walking) as between-subject variables. This was completed for all dependent variables.

To assess spatial changes, step length and stride width were examined. To assess temporal changes, cadence (steps per minute), stride velocity, and double-limb support time (DLST; seconds with both feet on the ground). Additionally, DLST and stride width were examined as indicators of stability (Hausdorff et al., 1998). Finally, gait variability was assessed using the coefficients of variation (standard deviation divided by the mean) for step length, step time, and stride velocity. Family-wise Bonferroni alpha adjustments were applied for the following families of DVs:

4. Spatial (step length, stride width)
5. Temporal (cadence, stride velocity, double-limb support time)
6. Variability (CV for step length, step time, stride velocity).

Thus, critical p values are as follows: 0.025 (spatial); 0.017 (temporal); and 0.017 (variability).

No dependent variables had significant effects of familiarity or beat perception ability; therefore, analyses were collapsed across these factors and 2x3 ANOVAs are reported. These ANOVAs include: instruction type (free walking, synchronized walking) and stimulus (metronome, low groove, high groove). For completeness, original 4-way analyses including

familiarity and beat perception ability are available in Appendix N.

Additional two-way mixed-design ANOVAs were completed on the raw data for each dependent variable to determine if cueing conditions or instructions significantly altered gait from baseline. Independent variables included instruction type (free walking, synchronized walking) and cueing condition (baseline [no cue], low groove, high groove, metronome). Where interactions were significant between instruction type and stimulus type, a follow-up one-way repeated measures ANOVA was conducted to identify the simple main effect.

Table 5.1. Demographic data for participants by subgroup.

	Free Walking			Synchronized Walking		
	Poor BP (n = 6)	Good BP (n = 4)	All (n = 10)	Poor BP (n = 4)	Good BP (n = 7)	All (n = 11)
Age (years)	72.3 (1.6)	68.75 (10.8)	70.9 (6.7)	67.3 (11.1)	66 (7)	66.5 (8.2)
Sex (M/F)	5/1	2/2	7/3	2/2	6/1	8/3
MDS-Unified PD Rating Scale (Section III)	42.5 (15.1)	29 (15.2)	37.1 (16.0)	35 (16.9)	32.4 (16.0)	33.4 (15.5)
Hoehn & Yahr Score	2.4 (0.5)	2.3 (0.5)	2.3 (	2.3 (0.5)	2.1 (0.4)	2.2 (0.4)
Timed-up-and-Go Test	12.9 (1.4)	10 (1.3)	11.705 (2)	12.8 (1.7)	10.5 (0.5)	11.4 (1.5)
Montreal Cognitive Assessment 7.2	24.8 (4.6)	26.3 (1.4)	25.4 (3.5)	26 (1.7)	26.9 (2.2)	26.5 (2.5)
Beat Alignment Test (% Accuracy)	53.9 (4.4)	80.9 (10)	64.7 (15.4)	54.4 (8.8)	75.6 (6.3)	67.9 (12.7)
Beck Depression Inventory	11.6 (2.8)	9 (2.9)	10.3 (2.9)	13.25 (10.6)	11 (4.7)	11.8 (6.9)
Beck Anxiety Inventory	6 (4.7)	11.5 (8.7)	8.2 (7.6)	10.5 (4.7)	10 (8.8)	10.8 (7.3)
Starkstein Apathy Scale	15 (2.8)	12.3 (4.5)	13.9 (3.6)	15 (4.5)	10.4 (5.5)	12.1 (5.4)
Goldsmith Musical Sophistication Index*	14.5 (7.2)	25.3 (13.1)	18.8 (10.8)	17.25 (9)	17.9 (7.3)	17.6 (7.5)
Dance Training (years)	0 (0)	0.3 (0.5)	0.3 (0.3)	0 (0)	1.8 (4.5)	1.1 (3.6)

Note. Means and standard deviations are presented for all items but sex (reported as male/female). *Goldsmith Musical Sophistication Index represents a norm referenced score of music training (out of 49). MDS = Movement Disorder Society.

5.2 Results

Demographics

A summary of demographic data for the two instruction groups is available in Table 5.1. A summary of raw descriptive statistics is available in Table 5.2 .

Table 5.2. Raw means and standard deviations for stimulus and instruction conditions.

	Baseline	Low Groove	High Groove	Metronome
Step Length (cm)				
Free Walking	58.2 (7.8)	55 (8.9) #	56.2 (9.3)	55 (9.3)
Synchronized Walking	59.3 (7)	57.6 (8.9) #	60.3 (8.6)	59.3 (7.3)
Stride Width (cm)				
Free Walking	7 (3.7)	8.1 (4) #	8 (4)	8.1 (4.1)
Synchronized Walking	7.3 (2.2)	7.8 (3.7) #	7.4 (2.5)	7.2 (2)
Cadence (steps/minute)				
Free Walking	109 (9.6)	106.3 (11.4)	110.6 (13.1)	109 (12.2)
Synchronized Walking	106.5 (5.7)	106.9 (11.9)	114.5 (9.6) *	115.1 (6.1) *
Stride Velocity (cm/sec)				
Free Walking	105.6 (18.9)	97.5 (20.8)	104 (24.2)	100.2 (23.4)
Synchronized Walking	105.1 (13.6)	103.9 (21.7)	115.4 (19.6)	113.3 (13.8) *
Double-Limb Support Time (sec)				
Free Walking	17.1 (2.3)	18.2 (2.8) #	17.8 (2.9)	18 (2.8)
Synchronized Walking	16.4 (1.5)	17.1 (2.8) #	16.3 (2.6)	16.3 (2.1)
Step Length Variability (CV)				
Free Walking	7.6 (2.9)	7.7 (2.7)	7.3 (2.8)	6.7 (2.2)
Synchronized Walking	6.1 (3.4)	5.9 (2.9)	5.5 (2.7)	5.6 (1.8)
Step Time Variability (CV)				
Free Walking	4.7 (1.5)	4.7 (1.2)	4.6 (1.4)	3.8 (0.9)
Synchronized Walking	5.4 (5)	4.4 (3.3)	4.1 (1.6)	3.7 (1.1)
Stride Velocity Variability (CV)				
Free Walking	5.7 (2.2)	5.4 (2.1)	5.3 (2.1)	5.2 (1.8)
Synchronized Walking	6 (4.8)	5 (2.9)	4.2 (2)	4.7 (1.4)

Note. Raw values for each dependent variable averaged across beat perception group and familiarity. All reported effects are significant at the family-wise corrected alpha levels reported in the study methods. * Denotes significant change from baseline for stimulus type within an instruction group (stimulus type interacted with instruction). # Denotes significant change from baseline when averaged across instruction groups (stimulus type did not interact with instruction).

5.2.1 Spatial Gait Parameters.

Step Length.

Overall, steps shortened from baseline. A 2x3 ANOVA indicated a significant main effect of stimulus on step length [F (1.8, 34.7) = 5.19, p = .013, $np2$ = .22]. Specifically, high groove cues produced significantly larger steps [M = -.011, SD = .07] than low groove [M = -.045, SD = .07] but not metronome cues [M = -.028, SD = .07]. Step length did not significantly differ between metronome and low groove cueing conditions (Figure 5.1 A).

Stride Width.

Results from the 4-way ANOVA indicated no significant effects of familiarity, groove, beat perception ability, or instructions on stride width (Figure 5.1B). Thus, no effects were collapsed for a 2x3 ANOVA. Statistics are available in Table 5.2.

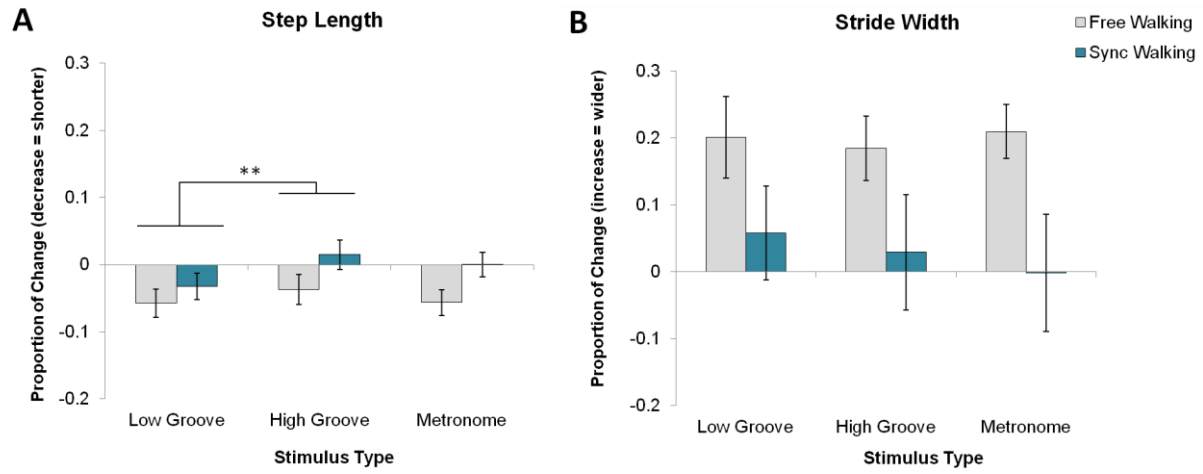


Figure 5.1. Mean normalized change scores and standard error for spatial measures. (A) Step length and (B) stride width are shown. ** Denotes a main effect of stimulus type at p < .01.

Table 5.3. 4-Way ANOVA results for stride width (cm).

	F Value	*p* Value	Effect Size (η_p^2)
Familiarity	2.312	.147	.120
Familiarity * Instruction	1.550	.230	.084
Familiarity *BP	2.856	.109	.144
Familiarity*Instruction*BP	1.117	.305	.062
Groove	.610	.446	.035
Groove*Instruction	.082	.777	.005
Groove*BP	.133	.720	.008
Groove*Instruction*BP	.036	.852	.002
Familiarity*Groove	1.819	.195	.097
Familiarity*Groove*Instruction	.067	.799	.004
Familiarity*Groove*BP	.629	.439	.036
Familiarity*Groove*Instruction*BP	.434	.519	.025
Instruction	2.312	.147	.120
BP	.025	.875	.001
Instruction*BP	.227	.640	.013

Note. Bonferroni alpha adjustments were applied to adjust for multiple comparisons among spatial gait parameters; thus, the critical alpha value is 0.025. BP = Beat Perception.

5.2.2 Temporal Gait Parameters.

Cadence.

A 2x3 ANOVA with stimulus (metronome, low groove, high groove) and instruction type (free walking, synchronized walking) showed a significant main effect of stimulus type [F (1.6, 30) = 11.5, $p < .001$, *np2* = .38]. Participants took significantly more steps per minute with high groove [M = .05, SD = .07] and metronome cues [M = .04, SD = .06] than with low groove cues [M =.01, SD = .07]. Cadence did not differ between the metronome and high groove cue condition (Figure 5.2A). No significant effects of instruction were present following multiple comparison correction.

Stride Velocity.

A 2x3 ANOVA indicated a significant main effect of both stimulus type [F (1.7, 32.2) = 11.30, p < .001, $np2$ = .37] and instruction type F (1, 19) = 7.47, p = .013, $np2$ = .28]. Stride velocity was significantly faster for both high groove [M = .04, SD = .12] and metronome cues [M = .06, SD = .10] than for low groove cues [M = -.05, SD = .11]. Instructions to synchronize [M = .05, SD = .09] were associated with faster velocity than instructions to walk freely [M = -.05, SD = .09] (Figure 5.2B).

Double-Limb Support Time (DLST).

Results from a 2x3 ANOVA indicate that stimulus type influenced DLST [F (1.5, 27.7) = 7.74, p < .01, $np2$ = .29]. Specifically, high groove cues [M = .01, SD = .06] yielded significantly lower DLST than both metronome [M = .02, SD = .05] and low groove cues [M = .05, SD = .07]. Metronome cues elicited significantly less DLST than low groove cues but significantly more DLST than high groove cues (Figure 5.2C).

5.2.3 Variability Gait Parameters.

There were no significant effects for any of the four factors on coefficient of variation for step length (Figure 5.3A), step time (Figure 5.3B), or stride velocity (Figure 5.3C). Therefore, these analyses were not rerun as 2x3 ANOVAs with instruction and stimulus type. For completeness, Table 5.4 presents the statistics from the initial 4-way ANOVAs.

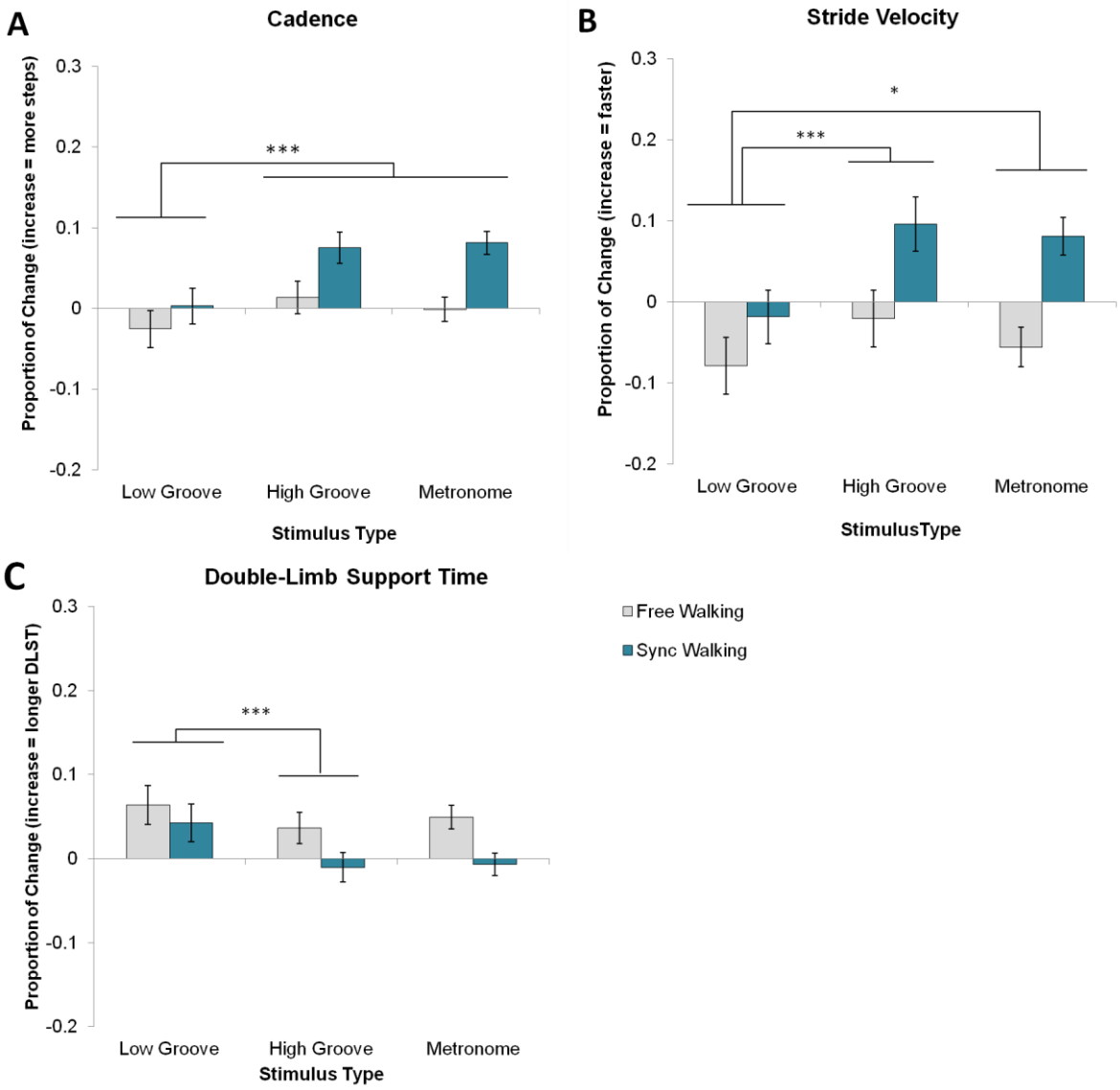


Figure 5.2. Mean normalized change scores and standard error for temporal gait measures. (A) cadence, (B) stride velocity, and (C) double-limb support time are shown. * Denotes a main effect of stimulus type significant at $p < .001$. * Denotes significance at $p < .05$.**

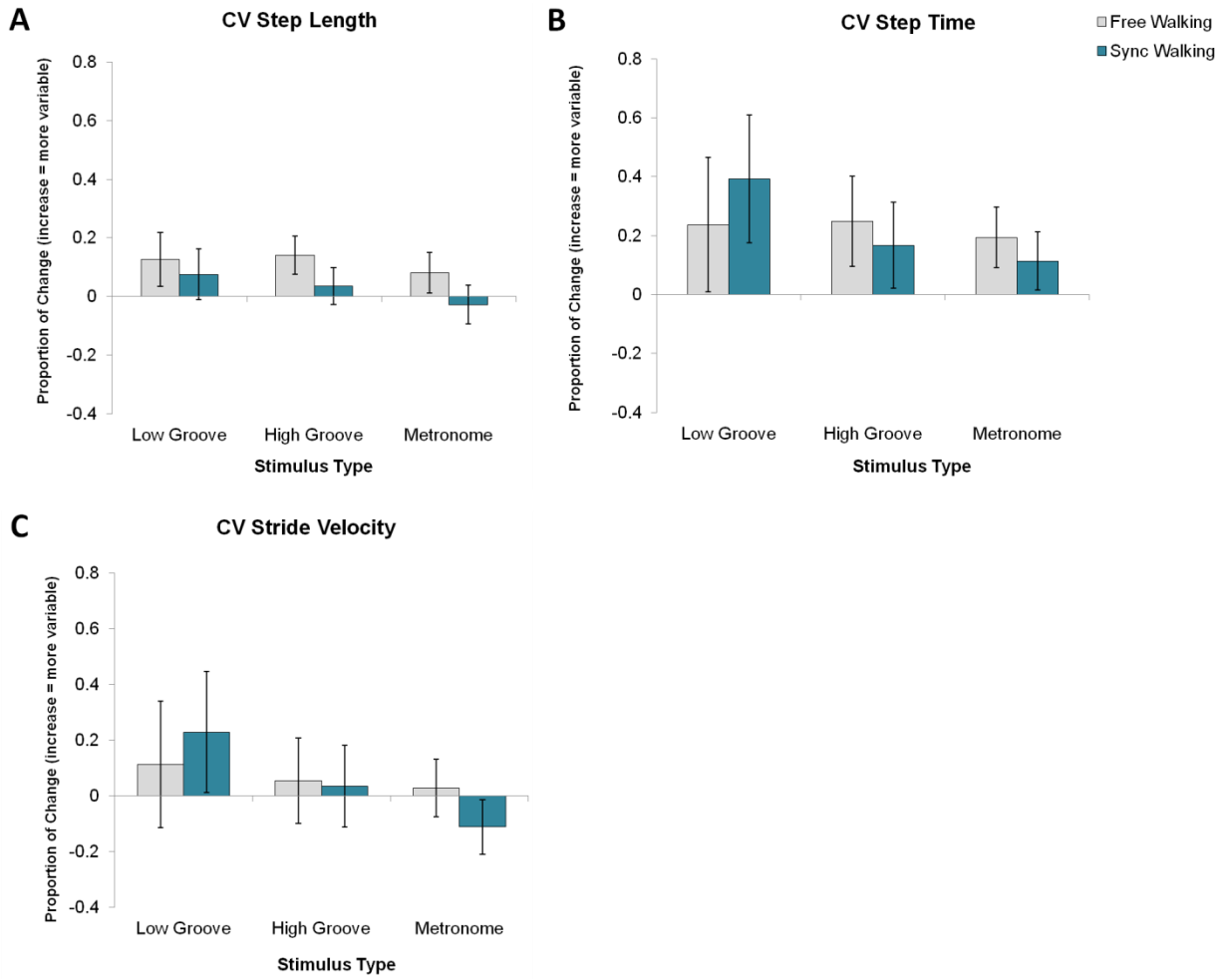


Figure 5.3. Mean normalized change scores and standard error for variability measures. No effects of stimulus type nor instruction reached significance for (A) CV step length, (B) CV step time, or (C) CV stride velocity.

Table 5.4. 4-Way ANOVA results for variability measures (CV of step length, step time, and stride velocity).

	Step Length Variability (CV)			Step Time Variability (CV)			Stride Velocity Variability (CV)		
	F Value	*p* Value	Effect Size (η_p^2)	*F* Value	*p* Value	Effect Size (η_p^2)	*F* Value	*p* Value	Effect Size (η_p^2)
Familiarity	5.021	.039	.228	.506	.486	.029	1.223	.284	.067
Familiarity * Instruction	.001	.979	.000	.057	.815	.003	.360	.556	.021
Familiarity *BP	.819	.378	.046	.636	.436	.036	.087	.772	.005
Familiarity*Instruction*BP	4.649	.046	.215	1.116	.306	.062	3.112	.096	.155
Groove	.091	.767	.005	1.257	.278	.069	3.133	.095	.156
Groove*Instruction	.403	.534	.023	2.214	.155	.115	.701	.414	.040
Groove*BP	.003	.956	.000	.039	.846	.002	.329	.574	.019
Groove*Instruction*BP	.000	.985	.000	1.646	.217	.088	.000	.990	.000
Familiarity*Groove	2.034	.172	.107	.950	.343	.053	.051	.823	.003
Familiarity*Groove*Instruction	.650	.431	.037	.001	.981	.000	.117	.737	.007
Familiarity*Groove*BP	.288	.598	.017	.667	.425	.038	.005	.947	.000
Familiarity*Groove*Instruction*BP	4.469	.050	.208	.793	.386	.045	.478	.498	.027
Instruction	.416	.528	.024	.014	.907	.001	.004	.953	.000
BP	.086	.773	.005	.000	.998	.000	.685	.419	.039
Instruction*BP	.044	.837	.003	.145	.708	.008	.254	.621	.015

Note. Bonferroni alpha adjustments were applied to adjust for multiple comparisons; thus, the critical alpha value is 0.017. BP = Beat Perception.

5.3 Discussion

The current study examined how gait in PD is influenced by musical properties, beat perception ability, and instructions to synchronize during accelerated music-based RAS. Good and poor beat perceivers were randomized to either walk freely or synchronize with the beat in auditory cues that ranged in perceived groove and familiarity, at 10% faster than individual walking rate. As predicted, perceived groove significantly affected gait outcomes. High groove cues elicited faster gait speed, longer steps, higher cadence, and lower DLST than low groove cues. Thus, high groove cues produced more favourable gait outcomes than low groove cues. In a similar vein, instructions to synchronize with cues were associated with an overall higher velocity than instructions to walk comfortably. Contrary to the hypothesis, this effect did not appear to interact with beat perception ability, which may suggest that instructions to synchronize are not strongly associated with dual-task interference among poor beat perceivers with PD.

5.3.1 Groove Alters Gait in PD

Overall, high groove cueing positively affected gait when compared to low groove cueing. High groove cues elicited faster overall gait speed with lower DLST, higher cadence, and longer steps than did low groove cues. These findings are similar to those observed in healthy young adults (Leow et al., 2014; Leow et al., 2015; Ready et al., 2019) and the healthy older adults in Chapter 4 of this dissertation. This supports the notion that low groove cues do not achieve the same gait outcomes as high groove cues, and that they should not be used interchangeably during therapeutic RAS. An important observation is that low groove cues increased stride width and DLST, and decreased step length, significantly from baseline. Therefore, low groove cues were both less effective than high groove cues at normalizing gait and had potential to worsen it by further shortening steps and potentially negatively impacting gait stability.

5.3.2 Music and Metronome RAS

Metronome cues did not significantly differ from high groove cues for any gait parameter. This is in line with several studies suggesting that high groove and metronome

cues yield similar findings (Leow et al., 2014; Leow et al., 2015). In addition, the fact that people with PD responded similarly to both high groove and metronome cues supports the conclusion from de Bruin et al. (2010) that music is a viable alternative to metronome cues during RAS. Importantly, the findings that metronome cues (like high groove cues) elicit faster velocity and higher cadence than low groove cues suggests that not *all* music is a viable option. Thus, groove should be carefully considered when recommending RAS as a therapeutic intervention.

5.3.3 Synchronizing Enhances RAS in PD

This study demonstrates that instructions to synchronize were associated with greater increases in velocity and cadence than instructions to walk freely with music in the background. As indicated in Chapter 1 of this dissertation, few studies have examined the importance of these instructions to synchronize on RAS outcomes in PD. The findings in this study that synchronized walkers significantly increased gait velocity and cadence from baseline, but free walkers did not, supports that instructions to synchronize may be crucial for entrainment among people with PD during RAS interventions. Furthermore, this study supports that attempting to synchronize to auditory cues does not negatively impact gait in people with PD. In this study, synchronized walking was not associated with deterioration in stability related parameters (e.g., DLST, stride width) or parameters linked to higher fall risk (i.e., step length or step time variability).

5.3.4 Beat perception and Dual-Tasking

It was hypothesized that poor beat perceivers would demonstrate worsening of gait parameters while synchronizing, as finding and matching the beat could create dual-task interference. This was not the case, as indicated by absence of effects associated with beat perception ability, instructions to synchronize, and familiarity. The sample size in this study was relatively small, and multiple comparison corrections were applied to limit the chance of type I error. Thus it is possible that effects exist but were not captured in this study. Furthermore, restricting the sample to only participants that are still able to ambulate safely without a mobility device may also limit the extent to which this sample demonstrates the typical PD vulnerability to dual-task interference.

However, it is also possible that people with mild-moderate PD are not negatively impacted by this task. Ready et al. (2019) suggested that people with poorer beat perception ability may rely more on other musical properties, rather than the beat, when walking to music, which is one possible explanation for the lack of effect. A similar suggestion was made by Grahn and Brett (2009), stating that perhaps people with PD do not as effectively use beat structure to enhance performance on rhythm-based tasks. However, in a task that uses real world music, as in this study, perhaps people with PD mitigate beat perception impairments by using other acoustic information (e.g., changes in amplitude or percussion) that instead contribute to musical properties such as perceived groove. Another possibility is that poor beat perceivers are not actually aware of any difficulty with beat finding or any discrepancy between the perceived versus the actual beat. As a result, their gait pattern is not altered when tasked with synchronizing.

An additional possibility for no effects of beat perception ability in this study, which is not mutually exclusive with those above, may be related to the cue pace. Participants were cued at 10% faster than baseline, rather than 15% faster, because of the shortening of steps observed in Studies 1 and 2. Two studies suggesting that poor beat perception ability negatively impacts gait during RAS cued participants at 15-22.5% faster than baseline (Leow et al., 2014; Leow et al., 2015); therefore, it the task of synchronizing may have been more difficult than in the current study. This explanation would be further supported findings from Ready et al. (2019), in which participants were cued at their baseline walking pace. Poor beat perceivers walked similarly when walking freely and synchronizing. Thus, synchronizing to a beat rate that is comfortably within baseline cadence may be less demanding and therefore less likely to pose dual-task interference.

5.3.5 Accelerated Auditory Cues Do Not Increase Step Length

Shortened strides are one of the primary gait changes in PD (Morris, Iansek, Matyas, & Summers, 1996). Therefore, the aim of rehabilitative gait strategies is not just to increase speed or stability, but also to help normalize stride or step length. The findings in this study that step length does not increase with cues corroborate previous RAS research on

PD suggesting that auditory cues at accelerated tempi do not increase step length. Importantly, they also suggest that using high groove stimuli may not change step length.

Researchers and clinicians should consider how increased gait velocity and cadence affect more complex gait symptoms in the absence of concomitant increases in stride length. As an example, festination is characterized by taking increasingly rapid and short steps, potentially in an attempt to recover center of gravity that is displaced anterior to the base of support (Giladi, Shabtai, Rozenberg, & Shabtai, 2001; Morris, Iansek, & Galna, 2008; Nonnekes, Giladi, Guha, & Fietzek, 2019). If accelerated auditory cueing leads to more rapid step rate and gait speed without increasing step length, this could increase the risk of festination. The exact causes of gait festination are still not well known (Nonnekes et al., 2019), which makes it difficult to predict how it would be influenced by the increased velocity and cadence associated with accelerated RAS. One possible outcome is that cueing allows people with PD to increase speed and cadence in a safe and stable way without progressively increasing cadence toward festination. However, I am not aware of any studies examining the impact of auditory cueing on festination (likely due in part to the safety risks associated with this research); therefore this should not be assumed. To negate any possibility that increasing gait speed but not step length could increase the likelihood of festination, future research should explore how accelerated auditory cues could be paired with additional strategies to increase step length.

5.4 Conclusions

The purpose of this study was to understand how beat perception ability, groove, and familiarity influenced gait outcomes in people with PD when synchronizing and walking freely to RAS cues that were 10% faster than baseline walking rate. Overall, groove and instructions to synchronize did influence gait outcomes, with high groove cues and instructions to synchronize fostering faster overall gait patterns. However, beat perception ability and stimulus familiarity had little effect on how people with PD modified gait when walking to accelerated auditory cues. Step length did not increase with gait velocity and cadence, indicating that further exploration is needed to determine how best to increase stride length in conjunction with gait speed.

References

Aragon, A., & Kings, J. (2018). *Occupational Therapy for People with Parkinson's*. Retrieved from London, UK: www.rcot.co.uk

Bugalho, P., Alves, L., & Miguel, R. (2013). Gait dysfunction in Parkinson's disease and normal pressure hydrocephalus: a comparative study. *Journal of Neural Transmission, 120*(8), 1201-1207. doi:10.1007/s00702-013-0975-3

Cameron, D. J., Pickett, K. A., Earhart, G. M., & Grahn, J. A. (2016). The Effect of Dopaminergic Medication on Beat-Based Auditory Timing in Parkinson's Disease. *Frontiers in Neurology, 7*(19). doi:10.3389/fneur.2016.00019

Dalla Bella, S., Benoit, C. E., Farrugia, N., Keller, P. E., Obrig, H., Mainka, S., & Kotz, S. A. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Sci Rep, 7*, 42005. doi:10.1038/srep42005

Dalla Bella, S., Dotov, D., Bardy, B., & Cock Valérie, C. (2018). Individualization of music-based rhythmic auditory cueing in Parkinson's disease. *Annals of the New York Academy of Sciences, 0*(0). doi:10.1111/nyas.13859

de Bruin, N., Doan, J. B., Turnbull, G., Suchowersky, O., Bonfield, S., Hu, B., & Brown, L. A. (2010). Walking with Music Is a Safe and Viable Tool for Gait Training in Parkinson's Disease: The Effect of a 13-Week Feasibility Study on Single and Dual Task Walking. *Parkinson's Disease, 2010*, 1-9. doi:10.4061/2010/483530

Deane, K. H. O., Ellis-Hill, C., Dekker, K., Davies, P., & Clarke, C. E. (2003). A Delphi Survey of Best Practice Occupational Therapy for Parkinson's Disease in the United Kingdom. *British Journal of Occupational Therapy, 66*(6), 247-254. doi:10.1177/030802260306600603

Ebersbach, G., Moreau, C., Gandor, F., Defebvre, L., & Devos, D. (2013). Clinical syndromes: Parkinsonian gait. *Movement Disorders, 28*(11), 1552-1559. doi:10.1002/mds.25675

Fahn, S. (1999). Parkinson disease, the effect of levodopa, and the elldopa trial. *Archives of Neurology, 56*(5), 529-535. doi:10.1001/archneur.56.5.529

Ghai, S., Ghai, I., Schmitz, G., & Effenberg, A. O. (2018). Effect of rhythmic auditory cueing on parkinsonian gait: A systematic review and meta-analysis. *Sci Rep, 8*(1), 506. doi:10.1038/s41598-017-16232-5

Giladi, N., Shabtai, H., Rozenberg, E., & Shabtai, E. (2001). Gait festination in Parkinson's disease. *Parkinsonism and Related Disorders, 7*(2), 135-138. doi:10.1016/S1353-8020(00)00030-4

Grahn, J. A., & Brett, M. (2009). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex, 45*(1), 54-61. doi:10.1016/j.cortex.2008.01.005

Hausdorff, J. M., Cudkowicz, M. E., Firtion, R., Wei, J. Y., & Goldberger, A. L. (1998). Gait variability and basal ganglia disorders: stride-to-stride variations of gait cycle timing in Parkinson's disease and Huntington's disease. *Mov Disord, 13*. doi:10.1002/mds.870130310

Hung, A., & Schwarzschild, M. (2014). Treatment of Parkinson's Disease: What's in the Non-dopaminergic Pipeline? *Neurotherapeutics, 11*(1), 34-46. doi:10.1007/s13311-013-0239-9

Keus, S. H. J., Bloem, B. R., Hendriks, E. J. M., Bredero-Cohen, A. B., & Munneke, M. (2007). Evidence-based analysis of physical therapy in Parkinson's disease with recommendations for practice and research. *Movement Disorders, 22*(4), 451-460. doi:10.1002/mds.21244

Leow, L.-A., Parrott, T., & Grahn, J. A. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Leow, L.-A., Rinchon, C., & Grahn, J. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *Annals of the New York Academy of Sciences, 1337*(1), 53-61. doi:10.1111/nyas.12658

Leow, L.-A., Waclawik, K., & Grahn, J. A. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research, 236*(1), 99-115. doi:10.1007/s00221-017-5110-5

Marr, J.-a. (1991). The Experience Of Living With Parkinson's Disease. *Journal of Neuroscience Nursing, 23*(5), 325-329.

Morris, M., Iansek, R., Matyas, T. A., & Summers, J. J. (1996). Stride length regulation in Parkinson's disease. Normalization strategies and underlying mechanisms. *Brain, 119*(2), 551-568.

Morris, M. E., Iansek, R., & Galna, B. (2008). Gait festination and freezing in Parkinson's disease: Pathogenesis and rehabilitation. *Movement Disorders, 23*(S2), S451-S460. doi:10.1002/mds.21974

Mullensiefen, D., Gingras, B., Musil, J., & Stewart, L. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. *PLoS ONE, 9*, e89642.

Nonnekes, J., Giladi, N., Guha, A., & Fietzek, U. M. (2019). Gait festination in parkinsonism: introduction of two phenotypes. *Journal of Neurology, 266*(2), 426-430. doi:10.1007/s00415-018-9146-7

Patterson, K. K., Wong, J. S., Knorr, S., & Grahn, J. A. (2018). Rhythm Perception and Production Abilities and Their Relationship to Gait After Stroke. *Arch Phys Med Rehabil, 99*(5), 945-951. doi:10.1016/j.apmr.2018.01.009

Ready, E. A., McGarry, L. M., Rinchon, C., Holmes, J. D., & Grahn, J. A. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait & Posture, 68*, 555-561. doi:https://doi.org/10.1016/j.gaitpost.2018.12.038

Schaafsma, J. D., Giladi, N., Balash, Y., Bartels, A. L., Gurevich, T., & Hausdorff, J. M. (2003). Gait dynamics in Parkinson's disease: relationship to Parkinsonian features, falls and response to levodopa. *Journal of the Neurological Sciences, 212*(1-2), 47-53. doi:10.1016/S0022-510X(03)00104-7

Schrag, A., Jahanshahi, M., & Quinn, N. (2000). How does Parkinson's disease affect quality of life? A comparison with quality of life in the general population. *Movement Disorders, 15*(6), 1112-1118. doi:10.1002/1531-8257(200011)15:6<1112::AID-MDS1008>3.0.CO;2-A

Soundy, A., Stubbs, B., & Roskell, C. (2013). *The Experience of Parkinson's Disease: A Systematic Review and Meta-Ethnography* (Vol. accepted manusript).

Sturkenboom, I. H. W. M., Thijssen, M. C. E., Gons-van Elsacker, J. J., Jansen, I. J. H., Maasdam, A., Schulten, M., . . . Munneke, M. (2008). *Guidelines for Occupational Therapy in Parkinson's Disease Rehabilitation*. Retrieved from Nijmegen, The Netherlands/Miami (FL), U.S.A.:

Švehlík, M., Zwick, E. B., Steinwender, G., Linhart, W. E., Schwingenschuh, P., Katschnig, P., . . . Enzinger, C. (2009). Gait Analysis in Patients With Parkinson's Disease Off Dopaminergic Therapy. *Archives of Physical Medicine and Rehabilitation, 90*(11), 1880-1886. doi:10.1016/j.apmr.2009.06.017

Tomlinson, C. L., Patel, S., Meek, C., Clarke, C. E., Stowe, R., Shah, L., . . . et al. (2012). Physiotherapy versus placebo or no intervention in Parkinson's disease. *Cochrane Database of Systematic Reviews*(7). doi:10.1002/14651858.CD002817.pub2

Chapter 6

6 General Discussion

The purpose of this dissertation was to examine how gait outcomes with RAS are influenced by an individual's perception of groove or familiarity with the stimulus, beat perception ability, and the task demands of synchronizing with an auditory stimulus. It was hypothesized that:

1. High groove cues would elicit faster gait with larger strides than low groove music.
2. Poor beat perceivers would benefit more from instructions to walk freely than to synchronize.
3. Higher familiarity would reduce negative impacts of synchronizing on poor beat perceivers.

Findings across all studies in this thesis support the first hypothesis, suggesting that perceived groove can significantly alter gait outcomes during music-based RAS across young and older adults without PD and people living with idiopathic PD. In particular, these findings suggest that high groove cues are better able to increase gait speed and cadence while maintaining step length than low groove cues. The second and third hypotheses were only partially supported by the findings in these studies, given that minimal effects were observed in relation to beat perception ability and familiarity that did not interact with instructions to synchronize.

The implications of these findings and other observations from these experiments will be reviewed below. In addition, limitations of this research that may have influenced the outcomes and possible future directions will be discussed.

6.1 Summary of Main Results

6.1.1 Groove in Music Alters Gait

Overall, higher perceived groove elicited more favourable gait outcomes in all three studies than did low groove cues. Most consistently, high groove cues were associated

with higher stride velocity and cadence compared to low groove cues. In addition, both healthy young adults and people with PD demonstrated larger step length with high groove cues than with low groove cues. In some cases, particularly among young adults, low groove cues were associated with an increase in gait variability compared to high groove cues. No significant effects of stimulus type on gait variability were observed in the healthy older adults or the adults with PD. These findings of increased gait speed, larger strides, higher cadence, and reduced gait variability in younger adults replicate previous findings in music-based RAS paradigms (Leow et al., 2015; Ready et al., 2019). Similar trends in the healthy older adults and PD participants in this dissertation support that the effects of groove on gait are relatively consistent across the lifespan and in people with PD. Furthermore, the finding of higher stepping rate, gait speed and, in some cases, step length support previous research suggesting that high groove music is associated with greater frequency and intensity of movements than low groove music (Janata et al., 2012).

High groove cues also frequently elicited better outcomes than metronome cues or, at the very least, elicited the same amount of change. These findings are in line with previous work suggesting that music can achieve the same effects as a metronome (de Bruin et al., 2015; Leow et al., 2015) or surpass them (Styns, van Noorden, Moelants, & Leman, 2007; Wittwer et al., 2013). In younger adults, high groove cues were associated with an improvement in spatial gait parameters compared to metronome cues. Temporal parameters, in contrast, only improved more for high groove compared to metronome when participants were synchronizing, but when free walking high groove and metronome cues elicited similar changes. For healthy older adults and people with PD, high groove cues and metronome cues did not differ statistically for any gait parameters. However, for older adults metronome cues were usually better than low groove cues (for cadence, velocity, DLST), but this was the case only for velocity and cadence in people with PD.

6.1.2 Instructions to Synchronize Enhance RAS Outcomes

Generally across studies, synchronized walkers were more likely to improve temporal gait parameters than those who walked freely. Among young adults, this frequently

interacted with stimulus type. Young synchronized walkers increased cadence and stride velocity more than free walkers for high groove cues. Among older adults, synchronizing elicited higher cadence, regardless of cue type. Similarly, people with PD only increased stride velocity or cadence significantly from baseline when synchronizing. Multiple studies have demonstrate that intent to synchronize results in more accurate gait synchronization with music (Leow et al., 2018; Mendonça et al., 2014), thus it is not surprising that synchronized walkers in the present studies increased cadence more than free walkers in these studies, as they were synchronizing with a stimulus that had a faster rate than their baseline. However, the last two experiments in this thesis are among the first to explicitly manipulate instructions to synchronize among older adults and people with Parkinson's disease during music-based RAS and support the use of these instructions to optimize outcomes.

Importantly, there were negative gait changes associated with synchronizing as well. Interestingly, these detriments were observed only in the young healthy group, not the older adults or PD group. Younger adults who were instructed to synchronize demonstrated higher step-to-step variability compared to free walkers. Leow et al. (2018) suggest that synchronizing gait is an inherently difficult task, as it requires whole body synchronization versus synchronization of an isolated extremity or digit (Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2014). In their study, Leow and colleagues found consistently that intent to synchronize negatively impacted gait, which they attribute to task difficulty. Nevertheless, several studies have found gait improvements among healthy adults with instructions to synchronize (Leow et al., 2015; Mendonça et al., 2014; Styns et al., 2007; Wittwer et al., 2013). This was the case in studies 1 and 2 for temporal gait parameters, but the changes in gait variability and step length among young adults suggests that the effects were not all beneficial. In this dissertation, the possibility that cue pace may have contributed to the difficulty of this task is proposed. Specifically, I suggest that increased variability and decreased step length may reflect attempts to modify the gait pattern to match a beat rate that is too fast to synchronize with comfortably. This may be supported by the findings that the synchronized participant groups did not, on average, tempo match but did adjust their cadence significantly more than free walking participants.

In contrast to these findings, people with PD did not demonstrate any negative effects in response to synchronizing instructions, despite generally being at a higher risk for dual-task interference (O'Shea et al., 2002; Yogev et al., 2005). The findings do not conclusively support that instructions to synchronize are better than instructions to walk freely among people with PD, as many of the gait parameters examined (e.g., stride length, DLST) did not differ based on instruction type. Numerically, it does appear that this could be the case (e.g., for cadence or stride width), but statistical significance was lacking for many dependent variables. Therefore this cannot be inferred and does not conclusively support previous findings that instructions to synchronize are required for effects in PD groups (Dotov et al., 2017; Hove, Suzuki, Uchitomi, Orimo, & Miyake, 2012). Nevertheless, the findings that synchronizing and not free walking significantly enhanced velocity and cadence from baseline without eliciting negative effects on stability supports that synchronized RAS can enhance rather than impair gait in mild to moderate PD without having detrimental effects (Benoit et al., 2014; Bryant, Rintala, Lai, & Protas, 2009).

6.1.3 The Challenge of Beat Finding During Synchronized RAS

Familiarity and beat perception ability had minimal impact on gait outcomes in these studies, which contradicted the hypothesis that poor beat perceivers would fare better with free walking instead of synchronized instructions and with high familiarity compared to low familiarity music. Only one, relatively small effect was observed for beat perception and familiarity in the healthy older adult group that may have resulted from increased cognitive demand. Older adults with poor beat perception shortened their strides more with unfamiliar stimuli than highly familiar stimuli, which may represent a cautious walking pattern and compensatory gait strategy when dual-tasking (Hak, Houdijk, Beek, & van Dieën, 2013; Hausdorff et al., 1998). Importantly, this effect did not interact with instruction, as was predicted and would be expected if beat finding for poor beat perceivers did truly elicit dual-task interference. This interaction had a relatively small effect size and, therefore, likely does not represent a marked detriment in gait stability. In addition, this effect did not manifest for other dependent variables that

can be indicative of stability or cautious walking, such as stride width, step variability, or gait speed (Herman, Hiladi, Gurevich, & Hausdorff, 2005; Nutt, 2001).

Notably, no effects for familiarity or beat perception ability were captured among PD participants. This was unexpected, as people with PD have been demonstrated to have overall poorer beat perception ability (Cameron et al., 2016; Grahn & Brett, 2009), more difficulty with sensorimotor synchronization (Bieńkiewicz & Craig, 2015; Miller et al., 2013), and to be more prone to dual-task interference while walking (Yogev et al., 2005). Thus, any difficulty with beat finding during synchronizing that impacts gait in a healthy group would be expected to more gravely impact the PD group. Given the small effect sizes observed in these healthy groups for beat perception/familiarity effects, it is possible that the PD study was not well powered enough to capture these effects with only twenty participants. There is research suggesting that there are patient subgroups in PD that may contribute to differences in temporal duration perception and production abilities (Merchant, Luciana, Hooper, Majestic, & Tuite, 2008; Miller et al., 2013). Miller et al. (2013) found that patterns of striatal dopaminergic denervation did not predict patterns of synchronization variability when tapping to an isochronous metronome but that it did predict sensorimotor synchronization accuracy. The authors suggest that these findings may explain some of the variable literature on temporal processing in PD, as such subgroups are rarely accounted for. These sources of heterogeneity in PD in sensorimotor performance and perceptual timing abilities are potential contributors to noise in small sample PD studies, such as the present one, and may explain the absence of findings related to beat perception abilities and synchronization during music-based RAS if such effects do exist. Two recent studies have suggested that other rhythmic abilities, not just perceptual beat ability, may predict if people with PD would be responders (demonstrate positive changes) or non-responders (demonstrate no change or deleterious change) to music-based RAS (Cochen De Cock et al., 2018; Dalla Bella et al., 2017). For example, the ability to adapt tapping tempo with a metronome or to maintain lower rates of tapping variability were associated with faster gait speed and longer strides with RAS. Both studies have highlighted the heterogeneity of PD participants in sensorimotor timing by dichotomizing participants into responder and non-responder groups. However, it should also be noted that markedly different cueing strategies were used compared to this

study (i.e., selecting cue rate that elicited the largest stride, superimposing metronome over music).

6.2 Implications for Clinical Practice

Although RAS is recommended in therapeutic guidelines for PD worldwide (Aragon & Kings, 2018; Keus et al., 2007; Sturkenboom et al., 2008), the specifics about how to best implement RAS are vague given the variable literature on RAS. The aim of this thesis was to elucidate how some factors known to influence sensorimotor outcomes with music may together influence RAS outcomes.

This dissertation supports that groove does, in fact, alter gait outcomes in people with PD. To date, the majority of research on groove and movement has been on healthy younger adults and, while informative, this could not be generalized to people with PD. The findings in this study support that maximizing groove in music during RAS can elicit immediate improvements in gait speed without shortening steps. Moreover, gait speed increased enough to be considered a moderate to large clinically meaningful change (Hass, Chris, Mark, Mariana, & Elizabeth, 2014). In other words, gait speed increased enough to result in a moderate to large reduction in the experience of disability among people with PD (Hass et al., 2014). This was also the case for metronome cues and supports that both metronome-based and high groove music-based RAS (at 10% faster than baseline) can have real therapeutic impacts on functional mobility. However, this research also suggests that low groove music produces a very different gait pattern than high groove cues. Therefore, high and low groove cues cannot be used interchangeably. Strides shortened, gait speed and cadence decreased, and stance widened more with low groove cues than at baseline (without auditory cueing). Not controlling for the level of perceived groove in music could have counterintuitive effects on gait in clinical practice despite the potential for music-based RAS to functionally improve gait.

High groove cues appear to potentially improve outcomes beyond what metronome cues would achieve, although this effect is less conclusive in the PD group. If high groove cues are not better than metronome cues but achieve the same outcomes, this still has a

number of positive implications for therapeutic RAS. This would indicate that opting to use a metronome will not limit the effects a user would achieve; this may be preferable to those who find compiling an appropriate music list to be cumbersome. However, it is promising that high groove music can be used as an alternative in cases where that is the user preference. Music is engaging, enjoyable, and stimuli can be changed as needed to maintain this engagement and facilitate therapeutic adherence (de Bruin et al., 2010). In addition, this may have potential to reduce the likelihood of habituation. Therefore, it may be advisable for therapists to recommend music over metronome cues to engage the user in therapy for ongoing gait management.

Furthermore, this dissertation suggests that synchronized RAS, to both high groove and metronome cues, may directly support temporal gait improvements associated with auditory cueing. In patients for whom the goal is to increase gait speed, encouraging synchronization between footfalls and the beat may therefore facilitate this change. Importantly, the potential benefits of instructions to synchronize should not override the significance of not cognitively overloading patients while ambulating. Therapists should use their clinical judgment when implementing auditory cues and monitor gait to confirm that the introduction of a synchronized RAS technique has not compromised gait stability.

These findings may also have clinical implications for conditions other than PD. The effects of groove on gait were largely consistent across all three groups studied in this dissertation, which suggests that the effects of perceived groove on movement may be more generalizable than we previously could have assumed with most findings being only in healthy young adults. RAS has been studied in a variety of clinical populations, including cerebral palsy, stroke, and multiple sclerosis (Cha et al., 2014; Kwak, 2007; Shahraki et al., 2017); further research on the role of groove in music in these populations may contribute to better gait outcomes with cueing.

Finally, clinicians should take caution that there are still many unanswered questions about what individual factors (e.g., cognitive decline) or task-related factors (e.g., frequency of use, cue pace) can alter the effects of both metronome- and music-based

RAS. This research, among many other recent studies, is a small step in the line of research that is required to understand how to properly individualize auditory cues to maximize gait outcomes in the safest way possible. Therefore, it is advisable that RAS should be used as an adjunct rehabilitative approach to increase functional mobility, and not to replace other strategies that may foster safe mobility, such as walker use. Therapists should monitor gait changes upon introduction of RAS, in particular if clients or caregivers express any concerns regarding their attention or stability while using RAS or if they have more severe motor symptoms that are less frequently studied with RAS.

6.3 Limitations

One general limitation of these studies is that only one cue pace was examined in each study, which does limit the generalizability of these findings to RAS at other cue rates. Cue rates of 15% faster in the healthy groups were originally selected based on research suggesting that cues at this rate successfully improve multiple gait parameters in both healthy and PD groups (Howe, Lovgreen, Cody, Ashton, & Oldham, 2003; Leow et al., 2014; Leow et al., 2015; McIntosh et al., 1997). As suggested in the first two study discussions, step shortening and increased variability, specifically in synchronized conditions associated with the greatest cadence adjustments, may indicate that the synchronization task was difficult. The use of only one tempo proportion across each study makes it difficult to disentangle this. In an attempt to reduce task difficulty in the PD group, the cue pace was lowered by 5% for the final study. Thus, participants were cued at 10% faster, instead of 15% faster. However, this may have contributed to differences observed among studies.

An additional limitation, which may be related to the one described above is the method for acquiring baseline gait data. We collected baseline gait measurements from a silent walking trial at the start of the study, in which participants were instructed to walk however felt normal and comfortable for them. Participants were not provided with an opportunity to walk without data being recorded to find their comfortable or normal walking rate. It may have been useful to provide participants with an opportunity to level out their walking rate to one that felt normal prior to beginning the trial. Thus, it is

possible that some participants unintentionally walked faster than their normal walking rate during baseline and were consequently cued at more than 15% faster than their comfortable walking speed.

With regards to the older adult study, it is a limitation that no measurements of cognition were collected during the experiment to demonstrate the cognitive status of participants, as this could influence outcomes (e.g., short-term memory impacting beat perception performance on Beat Alignment Test; Grahn & Schuit, 2012). Similarly, in both the older adult and PD study, no measures of exercise frequency were recorded. In healthy aging, and particularly in PD, exercise can influence outcomes on gait tasks (Plummer, Zukowski, Giuliani, Hall & Zurakowski, 2015; Shen, Wong-Yu & Yak, 2016); therefore, this information would have been helpful to understanding the profile of our samples.

There are multiple limitations in the PD study, given the challenges associated with studying clinical populations. Firstly, the sample size was small and there were a significant number of comparisons, not all of which were within subject manipulations. Multiple comparison corrections were applied to reduce the likelihood of interpreting false effects; however, this does also contribute to the possibility of not detecting true effect (type II error) with smaller effect sizes. Additionally, due to the variable nature of PD, and potential differences associated with freezing of gait (Nanhoe-Mahabier et al., 2011; Willems et al., 2006), participants who experience this symptom were excluded from the study even if still able to ambulate without a mobility aid. Similarly, participants with advanced enough symptoms to require a mobility aid were not registered in the study (Kegelmeyer, Parthasarathy, Kostyk, White & Kloos, 2013). Finally, given the physical and cognitive demands of this study, participants who were not able to walk for an extended period unaided or whose peak “ON” phase was not long enough for the duration of the study were also excluded from the study. This limits the extent to which these findings can be generalized to the greater PD population. However, these findings are promising and do support that groove and synchronization should be further studied in more advanced PD groups who may benefit more from gait interventions.

Finally, a general limitation of this dissertation is that the studies were not designed in a way that facilitates clear comparisons across each of the populations examined (healthy younger, healthy older, and Parkinson's disease participants). Modifications to study protocol among the studies, such as lowering cue pace for the PD group or implementing practice trials for healthy older and PD participants, pose some challenges to statistically comparing the groups and clearly interpreting the findings. It is important to acknowledge that these analyses could inform how gait changes differently with auditory cues across the lifespan and in the presence of PD. A design that involves consistent manipulations across all groups and, thus, the ability to make clear comparisons when including group as a factor in the ANOVAs would allow more concrete conclusions to be made about how these groups are influenced differently by RAS. Although this statistical design could be completed across the present studies, it would be impossible to conclude that observed effects are not caused, at least in part, by the protocol differences across groups. Therefore, these comparisons were not completed.

For future research, it is important to consider what these analyses might inform. Comparing across groups may indicate if the magnitude of gait change differs for certain groups, if the pattern of results differs among groups, or could reveal significance among factors that are not detected when comparing only within a group. Such analyses could indicate if auditory cues have a greater or lesser impact depending on age or presence of disease or that the pattern of changes depends on age or disease. For example, when examining numerical patterns across groups, it appears that the proportion of change in gait variability outcomes increased more among the healthy groups when synchronizing than among the PD group. This suggests that healthy participants may have increased gait variability more when synchronizing than did PD participants. However, the statistical significance of this is unknown with the analyses included in this dissertation. Importantly, including group as a factor could also reveal effects among factors, (e.g., beat perception ability) that are not detected when comparing only within one population. In this dissertation, minimal effects of beat perception ability or familiarity were detected. However, it is possible that comparing across groups might reveal that the effects of auditory cues impact good and poor beat perceivers differently depending on group. For example, it could show that beat perception ability influences outcomes in the healthy

older and PD groups but not younger adults, who should be the least susceptible to dual tasking interference. If this were true, this would reflect a different pattern of results across groups and also highlight a finding that may not otherwise be detected when only comparing within each of the participant groups. In future, research that allows for such analyses and interpretations could further elucidate the differential effects of stimulus properties, instructions, and beat perception abilities on RAS outcomes.

6.4 Future Directions

This dissertation provides strong evidence for the impact of musical groove on motor output. Although groove has been discussed for a long time in the music literature, it is only relatively recently gaining attention in psychological sciences as researchers try to better understand the relationship between groove and movement and how we process groove. Interestingly, there is research suggesting that syncopation contributes to the perception of groove in music (Matthews, Witek, Heggli, Penhune, & Vuust, 2019; Witek, Clarke, Wallentin, Kringelbach, & Vuust, 2014). Syncopation is perceived when a note occurs on a down (or weak) beat instead of the expected strong beat location (Witek et al., 2014); thus, it is heavily dependent on temporal processing. For this reason, it is interesting that groove perception does not appear to be affected in PD and that groove has powerful effects on movement in this group. To date, there is little research on the underlying neural correlates of groove. However, this could be an informative line of future research about neural mechanisms in PD that are spared, especially when paired with behavioural findings on perception of or movement with groove in healthy and PD populations.

Instructions to synchronize with RAS may maximize the effects of auditory cues on gait, in particular for gait velocity, and instructions do not appear to negatively impact stability in the early stages of PD. Importantly, the findings across all three experiments do also suggest that synchronized RAS does not improve spatial gait parameters, particularly stride length. It may be relevant to consider whether modified versions of synchronized instructions could encourage entrainment with high groove music without overstressing the need to tempo match and triggering compensatory gait strategies such as stride

shortening. For example, instructing users to synchronize as well as they can while maintaining large strides or to move with the music as best possible without strictly instructing the need to match footfalls with the beat. These more flexible instructions could potentially encourage users to adjust body movements to the music, therefore facilitating temporal gait changes and an attentional shift away from automatic movement, without overloading available attentional resources or forcing people to produce a trade off. This could permit flexibility among those who require it, for example people for whom beat finding and/or beat matching is cognitively demanding.

There are additional kinetic and kinematic changes that accompany spatial and temporal gait changes in PD. Given the consistent findings that groove can alter, at the very least, temporal parameters in PD it may be worthwhile to investigate the changes that occur when walking to high groove music using alternative modalities such as motion capture and electromyography. For example, if groove is associated with greater intensity of movements (Janata et al., 2012) and significantly changes gait velocity in PD, it is likely also associated with changes in muscle activation patterns that are disrupted in PD. Thus it may influence other critical gait outcomes such as heel strike (Jenkins et al., 2009; Kimmeskamp & Hennig, 2001) or ground clearance (Morris, 2000), which are both markedly reduced in PD and contribute to fall risk (Morris, Huxham, McGinley, Dodd, & Iansek, 2001). An interesting, though anecdotal, observation from this dissertation is that many PD participants appeared to increase their bilateral arm swing while walking with auditory cues from what was observed during the UPDRS motor exam. Arm swing during gait helps to preserve stability (Bruijn et al., 2010; Pijnappels et al., 2010); however, it is significantly impaired in PD and is highly correlated with falls. Arm swing amplitude has been reported to improve with auditory cues (Son & Kim, 2015), but there is very little literature to support this finding or that indicates how this relates to gait and balance changes with auditory cues. Future research should explore how high groove auditory cues can influence these other motor behaviours in PD.

In addition, as previously mentioned, the findings in this study cannot be generalized to later-stage PD groups with more severe symptoms and it is difficult to predict how groove would impact them. For example, postural instability and rigidity are worse in

more severe PD, and there may be physiological limitations with generating the motor output that was observed in other groups. In contrast, gait is more impaired and may be more easily modified. Research should also address how cognitive changes, which can worsen with disease progression (Roheger, Kalbe, Liepelt-Scarfone, 2018), impact the efficacy of synchronizing with high groove auditory cues. In particular, this may warrant further research into how beat perception ability and familiarity influence gait outcomes in these more advanced disease stages, where temporal processing, tolerance for dual-tasking, and cognitive abilities such as memory or attention are more severely affected.

6.5 Conclusions

The aim of the research undertaken in this dissertation was to explore how perception of musical properties (groove and familiarity) impact gait outcomes among people with good and poor beat perception, both when walking with demands to synchronize and when walking freely. The purpose of this was to contribute to our knowledge on what factors in RAS may need to be accounted for to optimize and individualize treatment in PD. The studies in this thesis are the first to investigate these factors together in accelerated music-based auditory cueing, particularly among older adult and Parkinson's disease populations. This research supports overall that high groove music and metronome cues have markedly different effects on spatiotemporal gait parameters than do low groove cues, and that low groove cues have the potential to hinder spatial and temporal gait parameters. This indicates that music in RAS should be carefully assessed before use. Furthermore, the findings in these studies support that synchronizing to RAS may be helpful to maximize the effects of cueing on temporal gait parameters across healthy adults and the PD group. However, these studies also highlight the various ways in which synchronizing can potentially compromise gait (e.g., shortening strides, increasing variability) and that this is not necessarily dependent on how well one can find a musical beat. Further research is required to understand what additional factors can be manipulated to best individualize music-based RAS for optimal gait management in clinical populations.

References

Aboutorabi, Arazpour, Bahramizadeh, Hutchins, & Fadayevatan. (2016). The effect of aging on gait parameters in able-bodied older subjects: a literature review. *Aging Clinical and Experimental Research, 28*(3), 393-405. doi:10.1007/s40520-015-0420-6

Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn. (2011). Cognitive motor interference while walking: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews, 35*(3), 715-728. doi:10.1016/j.neubiorev.2010.08.008

Amboni, Barone, & Hausdorff. (2013). Cognitive contributions to gait and falls: evidence and implications. *Movement disorders : official journal of the Movement Disorder Society, 28*(11), 1520-1533. doi:10.1002/mds.25674

Aragon, & Kings. (2018). *Occupational Therapy for People with Parkinson's*. Retrieved from London, UK: www.rcot.co.uk

Balash, Peretz, Leibovich, Herman, Hausdorff, & Giladi. (2005). Falls in outpatients with Parkinson's disease. *Journal of Neurology, 252*(11), 1310-1315. doi:10.1007/s00415-005-0855-3

Beck, Epstein, Brown, & Steer. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology*, *56*(6), 893-897. doi:10.1037/0022-006X.56.6.893

Beck, Ward, Mendelson, Mock, & Erbaugh. (1961). An inventory for measuring depression. *Arch Gen Psychiatry, 4*, 561-571.

Benoit, Dalla Bella, Farrugia, Obrig, Mainka, & Kotz. (2014a). Musically cued gait-training improves both perceptual and motor timing in Parkinson's disease. *Front Hum Neurosci, 8*, 494. doi:10.3389/fnhum.2014.00494

Benoit, Dalla Bella, Farrugia, Obrig, Mainka, & Kotz. (2014b). Musically Cued Gait-Training Improves Both Perceptual and Motor Timing in Parkinson’s Disease. *Frontiers in Human Neuroscience, 8*(494). doi:10.3389/fnhum.2014.00494

Bieńkiewicz, & Craig. (2015). Parkinson's Is Time on Your Side? Evidence for Difficulties with Sensorimotor Synchronization. *Frontiers in Neurology, 6*, 249-249. doi:10.3389/fneur.2015.00249

Blin, Ferrandez, & Serratrice. (1990). Quantitative analysis of gait in Parkinson patients: increased variability of stride length. *J Neurol Sci*, *98*(1), 91-97.

Brown, de Bruin, Doan, Suchowersky, & Hu. (2010). Obstacle crossing among people with Parkinson disease is influenced by concurrent music. *Journal of Rehabilitation Research and Development, 47*(3), 225-231.

Bruijn, S. M., Meijer, O. G., Beek, P. J., & van Dieën, J. H. (2010). The effects of arm swing on human gait stability. *J. Exp. Biol. 213*, 3945–3952. doi: 10.1242/jeb.045112

Bryant, Rintala, Lai, & Protas. (2009). An evaluation of self-administration of auditory cueing to improve gait in people with Parkinson's disease. *Clinical Rehabilitation, 23*(12), 1078-1085. doi:10.1177/0269215509337465

Bugalho, Alves, & Miguel. (2013). Gait dysfunction in Parkinson's disease and normal pressure hydrocephalus: a comparative study. *Journal of Neural Transmission, 120*(8), 1201-1207. doi:10.1007/s00702-013-0975-3

Burger, Thompson, Luck, Saarikallio, & Toiviainen. (2014). Hunting for the beat in the body: on period and phase locking in music-induced movement. *Frontiers in Human Neuroscience, 8*(903). doi:10.3389/fnhum.2014.00903

Caetano, Lord, Schoene, Pelicioni, Sturnieks, & Menant. (2016). Age-related changes in gait adaptability in response to unpredictable obstacles and stepping targets. *Gait & Posture, 46*, 35-41. doi:https://doi.org/10.1016/j.gaitpost.2016.02.003

Callisaya, Beare, Phan, Blizzard, Thrift, Chen, & Srikanth. (2013). Brain structural change and gait decline: a longitudinal population-based study. *J Am Geriatr Soc, 61*(7), 1074-1079. doi:10.1111/jgs.12331

Cameron, Bentley, & Grahn. (2015). Cross-cultural influences on rhythm processing: reproduction, discrimination, and beat tapping. *Frontiers in psychology, 6*(366). doi:10.3389/fpsyg.2015.00366

Cameron, Pickett, Earhart, & Grahn. (2016). The Effect of Dopaminergic Medication on Beat-Based Auditory Timing in Parkinson's Disease. *Frontiers in Neurology, 7*(19). doi:10.3389/fneur.2016.00019

Cameron, Stewart, Pearce, Grube, & Muggleton. (2012). Modulation of Motor Excitability by Metricality of Tone Sequences. *Psychomusicology: Music, Mind, and Brain, 22*(2), 122-128. doi:10.1037/a0031229

Canadian Institute for Health Information. (2007). *The Burden of Neurological Diseases, Disorders and Injuries in Canada* Ottawa: CIHI.

Cha, Kim, & Chung. (2014). Immediate Effects of Rhythmic Auditory Stimulation with Tempo Changes on Gait in Stroke Patients. *Journal of Physical Therapy Science, 26*(4), 479-482. doi:10.1589/jpts.26.479

Chen, Penhune, & Zatorre. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cereb Cortex, 18*(12), 2844-2854. doi:10.1093/cercor/bhn042

Cochen De Cock, Dotov, Ihalainen, Bégel, Galtier, Lebrun, . . . Dalla Bella. (2018). Rhythmic abilities and musical training in Parkinson's disease: do they help? *NPJ Parkinson's disease, 4*, 8-8. doi:10.1038/s41531-018-0043-7

Dalla Bella, Benoit, Farrugia, Keller, Obrig, Mainka, & Kotz. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Sci Rep, 7*, 42005. doi:10.1038/srep42005

Dalla Bella, Dotov, Bardy, & Cock Valérie. (2018). Individualization of music-based rhythmic auditory cueing in Parkinson's disease. *Annals of the New York Academy of Sciences, 0*(0). doi:10.1111/nyas.13859

Dalla Bella, Sowi, & ski. (2015). Uncovering Beat Deafness: Detecting Rhythm Disorders with Synchronized Finger Tapping and Perceptual Timing Tasks. *Journal of Visualized Experiments*(97), e51761. doi:doi:10.3791/51761

de Bruin, Doan, Turnbull, Suchowersky, Bonfield, Hu, & Brown. (2010). Walking with Music Is a Safe and Viable Tool for Gait Training in Parkinson's Disease: The Effect of a 13-Week Feasibility Study on Single and Dual Task Walking. *Parkinson's Disease, 2010*, 1-9. doi:10.4061/2010/483530

de Bruin, Kempster, Doucette, Doan, Hu, & Brown. (2015). The effects of music salience on the gait performance of young adults. *Journal of Music Therapy, 52*(3), 394-419. doi:10.1093/jmt/thv009

de Lau, & Breteler. (2006). Epidemiology of Parkinson's disease. *Lancet Neurology, 5*(6), 525-535. doi:10.1016/S1474-4422(06)70471-9

Deane, Ellis-Hill, Dekker, Davies, & Clarke. (2003). A Delphi Survey of Best Practice Occupational Therapy for Parkinson's Disease in the United Kingdom. *British Journal of Occupational Therapy, 66*(6), 247-254. doi:10.1177/030802260306600603

DeLong. (1990). Primate models of movement disorders of basal ganglia origin. *Trends in Neurosciences, 13*(7), 281-285.

Donoghue, Cronin, Savva, O'Regan, & Kenny. (2013). Effects of fear of falling and activity restriction on normal and dual task walking in community dwelling older adults. *Gait & Posture, 38*(1), 120-124. doi:https://doi.org/10.1016/j.gaitpost.2012.10.023

Dotov, Bayard, Cochen de Cock, Geny, Driss, Garrigue, . . . Dalla Bella. (2017). Biologically-variable rhythmic auditory cues are superior to isochronous cues in fostering natural gait variability in Parkinson's disease. *Gait Posture, 51*, 64-69. doi:10.1016/j.gaitpost.2016.09.020

Dunlap, Perera, VanSwearingen, Wert, & Brach. (2012). Transitioning to a narrow path: The impact of fear of falling in older adults. *Gait & Posture, 35*(1), 92-95. doi:https://doi.org/10.1016/j.gaitpost.2011.08.013

Ebersbach, Moreau, Gandor, Defebvre, & Devos. (2013). Clinical syndromes: Parkinsonian gait. *Movement Disorders, 28*(11), 1552-1559. doi:10.1002/mds.25675

Ellis, Cavanaugh, Earhart, Ford, Foreman, & Dibble. (2011). Which measures of physical function and motor impairment best predict quality of life in Parkinson's disease? *Parkinsonism and Related Disorders, 17*(9), 693-697. doi:10.1016/j.parkreldis.2011.07.004

Fahn. (1999). Parkinson disease, the effect of levodopa, and the elldopa trial. *Archives of Neurology, 56*(5), 529-535. doi:10.1001/archneur.56.5.529

Fahn, Oakes, Shoulson, Kieburtz, Rudolph, Lang, . . . Parkinson Study. (2004). Levodopa and the Progression of Parkinson's Disease. *The New England Journal of Medicine, 351*(24), 2498-2508.

Farrer. (2006). Genetics of Parkinson disease: paradigm shifts and future prospects. *Nature Reviews. Genetics, 7*(4), 306-318. doi:http://dx.doi.org/10.1038/nrg1831

Fox, Katzenschlager, Lim, Barton, de Bie, Seppi, . . . Sampaio. (2018). International Parkinson and movement disorder society evidence-based medicine review: Update on treatments for the motor symptoms of Parkinson's disease. *Movement Disorders, 33*(8), 1248-1266. doi:10.1002/mds.27372

Gabell, & Nayak. (1984). The effect of age on variability in gait. *J Gerontol, 39*(6), 662-666.

Ghai, Ghai, & Effenberg. (2018a). Effect of Rhythmic Auditory Cueing on Aging Gait: A Systematic Review and Meta-Analysis. *Aging and disease, 9*(5), 901-923. doi:10.14336/AD.2017.1031

Ghai, Ghai, Schmitz, & Effenberg. (2018b). Effect of rhythmic auditory cueing on parkinsonian gait: A systematic review and meta-analysis. *Sci Rep, 8*(1), 506. doi:10.1038/s41598-017-16232-5

Giladi, Shabtai, Rozenberg, & Shabtai. (2001). Gait festination in Parkinson's disease. *Parkinsonism and Related Disorders, 7*(2), 135-138. doi:10.1016/S1353-8020(00)00030-4

Goetz, Fahn, Martinez-Martin, Poewe, Sampaio, Stebbins, . . . LaPelle. (2007). Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS): Process, format, and clinimetric testing plan. *Mov Disord, 22*(1), 41-47. doi:10.1002/mds.21198

Grafton. (2004). Contributions of functional imaging to understanding parkinsonian symptoms. *Current Opinion in Neurobiology, 14*(6), 715-719. doi:10.1016/j.conb.2004.10.010

Grahn, & Brett. (2009). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex, 45*(1), 54-61. doi:10.1016/j.cortex.2008.01.005

Grahn, & Rowe. (2009). Feeling the beat: premotor and striatal interactions in musicians and nonmusicians during beat perception. *J Neurosci, 29*(23), 7540-7548. doi:10.1523/jneurosci.2018-08.2009

Grahn, & Schuit. (2012). Individual Differences in Rhythmic Ability: Behavioral and Neuroimaging Investigations. *Psychomusicology, 22*(2), 105-121. doi:10.1016/S1364-6613(00)01538-2

Gupta. (2002). Anatomy and physiology of the Basal Ganglia. *Psychiatric Annals, 32*(4), 230-232.

Hak, Houdijk, Beek, & van Dieën. (2013). Steps to take to enhance gait stability: the effect of stride frequency, stride length, and walking speed on local dynamic stability and margins of stability. *PLoS ONE, 8*(12), e82842-e82842. doi:10.1371/journal.pone.0082842

Hass, Chris, Mark, Mariana, & Elizabeth. (2014). Defining the Clinically Meaningful Difference in Gait Speed in Persons With Parkinson Disease. *Journal of neurologic physical therapy, 38*(4).

Hausdorff, Cudkowicz, Firtion, Wei, & Goldberger. (1998). Gait variability and basal ganglia disorders: stride-to-stride variations of gait cycle timing in Parkinson's disease and Huntington's disease. *Mov Disord, 13*(3), 428-437. doi:10.1002/mds.870130310

Hausdorff, Edelberg, Mitchell, Goldberger, & Wei. (1997). Increased gait unsteadiness in community-dwelling elderly fallers. *Arch Phys Med Rehabil, 78*. doi:10.1016/s0003-9993(97)90034-4

Hausdorff, Rios, & Edelberg. (2001). Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Arch Phys Med Rehabil, 82*. doi:10.1053/apmr.2001.24893

Health Canada, & Parkinson Society Canada. (2003). *Parkinson's Disease: Social and Economic Impact*. Toronto: PSC.

Herman, Giladi, Gurevich, & Hausdorff (2005). *Gait & Posture, 21*(2), 178-185. doi:10.1016/j.gaitpost.2004.01.014

Hollman, Childs, McNeil, Mueller, Quilter, & Youdas. (2010). Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. *Gait & Posture, 32*(1), 23-28. doi:https://doi.org/10.1016/j.gaitpost.2010.02.017

Honma, Kuroda, Futamura, Shiromaru, & Kawamura. (2016). Dysfunctional counting of mental time in Parkinson's disease. *Sci Rep, 6*, 25421. doi:10.1038/srep25421

https://www.nature.com/articles/srep25421#supplementary-information

Hove, Suzuki, Uchitomi, Orimo, & Miyake. (2012). Interactive Rhythmic Auditory Stimulation Reinstates Natural 1/<italic>f</italic> Timing in Gait of Parkinson's Patients. *PLoS ONE, 7*(3), e32600. doi:10.1371/journal.pone.0032600

Howe, Lovgreen, Cody, Ashton, & Oldham. (2003). Auditory cues can modify the gait of persons with early-stage Parkinson's disease: a method for enhancing parkinsonian walking performance? *Clin Rehabil, 17*(4), 363-367. doi:10.1191/0269215503cr621oa

Hung, & Schwarzschild. (2014). Treatment of Parkinson's Disease: What's in the Non-dopaminergic Pipeline? *Neurotherapeutics, 11*(1), 34-46. doi:10.1007/s13311-013-0239-9

Inzelberg, Schechtman, & Paleacu. (2002). Onset age of Parkinson disease. *American Journal of Medical Genetics, 111*(4), 459-460. doi:10.1002/ajmg.10586

Janata, Tomic, & Haberman. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General, 141*(1), 54-75. doi:http://dx.doi.org/10.1037/a0024208

Jankovic. (2008). Parkinson's disease: clinical features and diagnosis. *Journal of Neurology, Neurosurgery & Psychiatry, 79*(4), 368-376. doi:10.1136/jnnp.2007.131045

Jenkins, Almeida, Spaulding, van Oostveen, Holmes, Johnson, & Perry. (2009). Plantar cutaneous sensory stimulation improves single-limb support time, and EMG activation patterns among individuals with Parkinson's disease. *Parkinsonism and Related Disorders, 15*(9), 697-702. doi:10.1016/j.parkreldis.2009.04.004

Kegelmeyer, D. A., Parthasarathy, S., Kostyk, S. K., White, S. E., & Kloos, A. D. (2013). Assistive devices alter gait patterns in parkinson disease: Advantages of the four-wheeled walker. *Gait & Posture, 38*(1), 20-24. doi:10.1016/j.gaitpost.2012.10.027

Keus, Bloem, Hendriks, Bredero-Cohen, & Munneke. (2007). Evidence-based analysis of physical therapy in Parkinson's disease with recommendations for practice and research. *Movement Disorders, 22*(4), 451-460. doi:10.1002/mds.21244

Kim, Allen, Canning, & Fung. (2013). Postural Instability in Patients with Parkinson's Disease: Epidemiology, Pathophysiology and Management. *CNS Drugs, 27*(2), 97-112. doi:10.1007/s40263-012-0012-3

Kimmeskamp, & Hennig. (2001). Heel to toe motion characteristics in Parkinson patients during free walking. *Clin Biomech (Bristol, Avon), 16*(9), 806-812.

Kotz, Schwartze, & Schmidt-Kassow. (2009). Non-motor basal ganglia functions: a review and proposal for a model of sensory predictability in auditory language perception. *Cortex, 45*(8), 982-990. doi:10.1016/j.cortex.2009.02.010

Kovacs. (2005). Age-Related Changes in Gait and Obstacle Avoidance Capabilities in Older Adults: A Review. *Journal of Applied Gerontology, 24*(1), 21-34. doi:10.1177/0733464804271279

Kung, Chen, Zatorre, & Penhune. (2013). Interacting cortical and basal ganglia networks underlying finding and tapping to the musical beat. *J Cogn Neurosci, 25*(3), 401-420. doi:10.1162/jocn_a_00325

Kwak. (2007). Effect of rhythmic auditory stimulation on gait performance in children with spastic cerebral palsy. *J Music Ther, 44*(3), 198-216.

. LabVIEW. Austin, TX: National Instruments.

Lai, Marion, Teschke, & Tsui. (2002). Occupational and environmental risk factors for Parkinson's disease. *Parkinsonism and Related Disorders, 8*(5), 297-309. doi:10.1016/S1353-8020(01)00054-2

Laughton, Slavin, Katdare, Nolan, Bean, Kerrigan, . . . Collins. (2003). Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait & Posture, 18*(2), 101-108. doi:https://doi.org/10.1016/S0966-6362(02)00200-X

Launay, Grube, & Stewart. (2014). Dysrhythmia: a specific congenital rhythm perception deficit. *Front Psychol, 5*, 18. doi:10.3389/fpsyg.2014.00018

Lee. (2017). Effects of single and dual tasks during walking on spatiotemporal gait parameters of community-dwelling older. *Journal of Physical Therapy Science, 29*(10), 1874-1877. doi:10.1589/jpts.29.1874

Leow, Parrott, & Grahn. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Leow, Rinchon, & Grahn. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *Annals of the New York Academy of Sciences, 1337*(1), 53-61. doi:10.1111/nyas.12658

Leow, Waclawik, & Grahn. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research, 236*(1), 99-115. doi:10.1007/s00221-017-5110-5

Lim, van Wegen, de Goede, Deutekom, Nieuwboer, Willems, . . . Kwakkel. (2005). Effects of external rhythmical cueing on gait in patients with Parkinson's disease: a systematic review. *Clinical Rehabilitation, 19*(7), 695-713. doi:10.1191/0269215505cr906oa

Limousin, & Martinez-Torres. (2008). Deep brain stimulation for Parkinson's disease. *Neurotherapeutics, 5*(2), 309-319. doi:10.1016/j.nurt.2008.01.006

Macphee, & Stewart. (2012). Parkinson's disease – pathology, aetiology and diagnosis. *Reviews in Clinical Gerontology, 22*(3), 165-178. doi:10.1017/S095925981200007X

Marr. (1991). The Experience Of Living With Parkinson's Disease. *Journal of Neuroscience Nursing, 23*(5), 325-329.

Matthews, Witek, Heggli, Penhune, & Vuust. (2019). The sensation of groove is affected by the interaction of rhythmic and harmonic complexity. *PLoS ONE, 14*, e0204539.

Maylor, & Wing. (1996). Age differences in postural stability are increased by additional cognitive demands. *J Gerontol B Psychol Sci Soc Sci, 51*. doi:10.1093/geronb/51B.3.P143

Mazzoni, Hristova, & Krakauer. (2007). Why Don't We Move Faster? Parkinson's Disease, Movement Vigor, and Implicit Motivation. *The Journal of Neuroscience, 27*(27), 7105. doi:10.1523/JNEUROSCI.0264-07.2007

McAuley, Daly, & Curtis. (2009). A preliminary investigation of a novel design of visual cue glasses that aid gait in Parkinson's disease. *Clinical Rehabilitation, 23*(8), 687-695. doi:10.1177/0269215509104170

McIntosh, Brown, Rice, & Thaut. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery and Psychiatry, 62*, 22-26. doi:10.1136/jnnp.62.1.22

Mendonça, Oliveira, Fontes, & Santos. (2014). The effect of instruction to synchronize over step frequency while walking with auditory cues on a treadmill. *Hum Mov Sci, 33*, 33-42. doi:10.1016/j.humov.2013.11.006

Merchant, Luciana, Hooper, Majestic, & Tuite. (2008). Interval timing and Parkinson's disease: heterogeneity in temporal performance. *Exp Brain Res, 184*(2), 233-248. doi:10.1007/s00221-007-1097-7

Miller, Kwak, Bohnen, Müller, Dayalu, & Seidler. (2013). The pattern of striatal dopaminergic denervation explains sensorimotor synchronization accuracy in Parkinson's disease. *Behavioural Brain Research, 257*, 100-110. doi:https://doi.org/10.1016/j.bbr.2013.09.032

Moore, Peretz, & Giladi. (2007). Freezing of gait affects quality of life of peoples with Parkinson's disease beyond its relationships with mobility and gait. *Movement Disorders, 22*(15), 2192-2195. doi:10.1002/mds.21659

Morris. (2000). Movement Disorders in People With Parkinson Disease: A Model for Physical Therapy. *Physical Therapy, 80*(6), 578-597. doi:10.1093/ptj/80.6.578

Morris, Huxham, McGinley, Dodd, & Iansek. (2001). The biomechanics and motor control of gait in Parkinson disease. *Clinical Biomechanics, 16*(6), 459-470. doi:10.1016/S0268-0033(01)00035-3

Morris, Iansek, & Galna. (2008). Gait festination and freezing in Parkinson's disease: Pathogenesis and rehabilitation. *Movement Disorders, 23*(S2), S451-S460. doi:10.1002/mds.21974

Morris, Iansek, Matyas, & Summers. (1996). Stride length regulation in Parkinson's disease. Normalization strategies and underlying mechanisms. *Brain, 119*(2), 551-568.

Morris, Martin, & Schenkman. (2010). Striding Out With Parkinson Disease: Evidence-Based Physical Therapy for Gait Disorders. *Physical Therapy, 90*(2), 280-288. doi:10.2522/ptj.20090091

Mullensiefen, Gingras, Musil, & Stewart. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. *PLoS ONE, 9*, e89642.

Müllensiefen, Gingras, Stewart, & Musil. (2014). *The Goldsmiths Musical Sophistication Index (Gold-MSI): Technical Report and Documentation v1.0*. Retrieved from London:

Nasreddine, Phillips, Bedirian, Charbonneau, Whitehead, Collin, . . . Chertkow. (2005). The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *J Am Geriatr Soc, 53*(4), 695-699. doi:10.1111/j.1532-5415.2005.53221.x

Nieuwboer, Kwakkel, Rochester, Jones, van Wegen, Willems, . . . Lim. (2007). Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. *Journal of Neurology, Neurosurgery & Psychiatry, 78*(2), 134-140. doi:10.1136/jnnp.200X.097923

Niv, Joel, & Dayan. (2006). A normative perspective on motivation. *Trends in Cognitive Sciences, 10*(8), 375-381. doi:10.1016/j.tics.2006.06.010

Nombela, Hughes, Owen, & Grahn. (2013). Into the groove: Can rhythm influence Parkinson's disease? *Neuroscience and Biobehavioral Reviews, 37*(10), 2564-2570. doi:10.1016/j.neubiorev.2013.08.003

Nonnekes, Giladi, Guha, & Fietzek. (2019). Gait festination in parkinsonism: introduction of two phenotypes. *Journal of Neurology*, *266*(2), 426-430. doi:10.1007/s00415-018-9146-7

Nutt, J. G. (2001). Classification of gait and balance disorders. *Adv Neurol, 87*, 119-133.

O'Shea, Morris, & Iansek. (2002). Dual task interference during gait in people with Parkinson disease: Effects of motor versus cognitive secondary tasks. *Physical Therapy, 82*(9), 888-897.

Pastor, Artieda, Jahanshahi, & Obeso. (1992). Time estimation and reproduction is abnormal in Parkinson's disease. *Brain, 115 Pt 1*, 211-225.

Patel, Jankovic, & Hallett. (2014). Sensory aspects of movement disorders. *Lancet Neurology, 13*(1), 100-112. doi:10.1016/S1474-4422(13)70213-8

Patterson, Wong, Knorr, & Grahn. (2018). Rhythm Perception and Production Abilities and Their Relationship to Gait After Stroke. *Arch Phys Med Rehabil, 99*(5), 945-951. doi:10.1016/j.apmr.2018.01.009

Perry, Carville, Smith, Rutherford, & Newham. (2007). Strength, power output and symmetry of leg muscles: effect of age and history of falling. *European Journal of Applied Physiology, 100*(5), 553-561. doi:10.1007/s00421-006-0247-0

Phillips-Silver, Toiviainen, Gosselin, Piché, Nozaradan, Palmer, & Peretz. (2011). Born to dance but beat deaf: A new form of congenital amusia. *Neuropsychologia, 49*(5), 961-969. doi:10.1016/j.neuropsychologia.2011.02.002

Pijnappels, M., Kingma, I., Wezenberg, D., Reurink, G., & van Dieën, J. H. (2010). Armed against falls: the contribution of arm movements to balance recovery after tripping. E*xp. Brain Res. 201*, 689–699. doi: 10.1007/s00221-009-2088-7

Plummer, P., Zukowski, L. A., Giuliani, C., Hall, A. M., & Zurakowski, D. (2015). Effects of physical exercise interventions on gait-related dual-task interference in older adults: A systematic review and meta-analysis. *Gerontology, 62*(1), 94-117. doi:10.1159/000371577

Podsiadlo, & Richardson. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc, 39*(2), 142-148.

Povel, & Essens. (1985). Perception of temporal patterns. [doi:10.2307/40285311]. US: University of California Press.

Priest, Salamon, & Hollman. (2008). Age-related differences in dual task walking: a cross sectional study. *Journal of NeuroEngineering and Rehabilitation, 5*(1), 29. doi:10.1186/1743-0003-5-29

Qualtrics. (2018). Provo, Utah, USA. Retrieved from https://www.qualtrics.com

Ready, McGarry, Rinchon, Holmes, & Grahn. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait & Posture, 68*, 555-561. doi:https://doi.org/10.1016/j.gaitpost.2018.12.038

Rennie, Löfgren, Moe-Nilssen, Opheim, Dietrichs, & Franzén. (2018). The reliability of gait variability measures for individuals with Parkinson's disease and healthy

older adults – The effect of gait speed. *Gait & Posture, 62*, 505-509. doi:https://doi.org/10.1016/j.gaitpost.2018.04.011

Roberts. (2017). *Comparing the influence of music enjoyment and beat perception ability on spatiotemporal gait parameters among healthy young and older adults.* (Master of Science), University of Western Ontario, Electronic Thesis and Dissertation Repository. Retrieved from https://ir.lib.uwo.ca/etd/4893 (4893)

Rocha, Porfírio, Ferraz, & Trevisani. (2014). Effects of external cues on gait parameters of Parkinson's disease patients: A systematic review. *Clinical Neurology and Neurosurgery, 124*, 127-134. doi:10.1016/j.clineuro.2014.06.026

Rochester, Hetherington, Jones, Nieuwboer, Willems, Kwakkel, & Van Wegen. (2005). The Effect of External Rhythmic Cues (Auditory and Visual) on Walking During a Functional Task in Homes of People With Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation, 86*(5), 999-1006. doi:10.1016/j.apmr.2004.10.040

Ruiz, Catalán, & Carril. (2011). Initial Motor Symptoms of Parkinson Disease. *The Neurologist, 17*, S18-S20. doi:10.1097/NRL.0b013e31823966b4

Schaafsma, Giladi, Balash, Bartels, Gurevich, & Hausdorff. (2003). Gait dynamics in Parkinson's disease: relationship to Parkinsonian features, falls and response to levodopa. *Journal of the Neurological Sciences, 212*(1-2), 47-53. doi:10.1016/S0022-510X(03)00104-7

Schapira. (2009). Neurobiology and treatment of Parkinson's disease. *Trends in Pharmacological Sciences, 30*(1), 41-47. doi:10.1016/j.tips.2008.10.005

Schrag, Jahanshahi, & Quinn. (2000). How does Parkinson's disease affect quality of life? A comparison with quality of life in the general population. *Movement Disorders, 15*(6), 1112-1118. doi:10.1002/1531-8257(200011)15:6<1112::AID-MDS1008>3.0.CO;2-A

Sethi. (2008). Levodopa unresponsive symptoms in Parkinson disease. *Movement Disorders, 23*(S3), S521-S533. doi:10.1002/mds.22049

Shahraki, Sohrabi, Taheri Torbati, Nikkhah, & NaeimiKia. (2017). Effect of rhythmic auditory stimulation on gait kinematic parameters of patients with multiple sclerosis. *J Med Life, 10*(1), 33-37.

Shulman, De Jager, & Feany. (2011). Parkinson's Disease: Genetics and Pathogenesis. *Annual Review of Pathology: Mechanisms of Disease, 6*, 193-222. doi:10.1146/annurev-pathol-011110-130242

Shen, X., Wong-Yu, I., & Mak, M. (2016). Effects of exercise on falls, balance, and gait ability in parkinson's disease: A meta-analysis. *Neurorehabilitation and Neural Repair, 30*(6), 512-527. doi:10.1177/1545968315613447

Skodda, Flasskamp, & Schlegel. (2010). Instability of syllable repetition as a model for impaired motor processing: is Parkinson's disease a "rhythm disorder"? *J Neural Transm (Vienna), 117*(5), 605-612. doi:10.1007/s00702-010-0390-y

Smith, Harper, Gittings, & Abernethy. (2007). The effect of Parkinson's disease on time estimation as a function of stimulus duration range and modality. *Brain Cogn, 64*(2), 130-143. doi:10.1016/j.bandc.2007.01.005

Sofuwa, Nieuwboer, Desloovere, Willems, Chavret, & Jonkers. (2005). Quantitative Gait Analysis in Parkinson's Disease: Comparison With a Healthy Control Group. *Archives of Physical Medicine and Rehabilitation, 86*(5), 1007-1013. doi:10.1016/j.apmr.2004.08.012

Son, & Kim. (2015). Kinematic analysis of arm and trunk movements in the gait of Parkinson's disease patients based on external signals. *Journal of Physical Therapy Science, 27*(12), 3783-3786. doi:10.1589/jpts.27.3783

Soundy, Stubbs, & Roskell. (2013). *The Experience of Parkinson's Disease: A Systematic Review and Meta-Ethnography* (Vol. accepted manusript).

Spaulding, Barber, Colby, Cormack, Mick, & Jenkins. (2013). Cueing and Gait Improvement Among People With Parkinson's Disease: A Meta-Analysis. *Archives of Physical Medicine and Rehabilitation, 94*(3), 562-570. doi:10.1016/j.apmr.2012.10.026

Starkstein, Mayberg, Preziosi, Andrezejewski, Leiguarda, & Robinson. (1992). Reliability, validity, and clinical correlates of apathy in Parkinson's disease. *J Neuropsychiatry Clin Neurosci, 4*(2), 134-139. doi:10.1176/jnp.4.2.134

Stupacher, Hove, & Janata. (2016). Audio Features Underlying Perceived Groove and Sensorimotor Synchronization in Music. *Music Perception: An Interdisciplinary Journal, 33*(5), 571. doi:10.1525/mp.2016.33.5.571

Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller. (2013). Musical groove modulates motor cortex excitability: A TMS investigation. *Brain and Cognition, 82*(2), 127-136. doi:https://doi.org/10.1016/j.bandc.2013.03.003

Sturkenboom, Thijssen, Gons-van Elsacker, Jansen, Maasdam, Schulten, . . . Munneke. (2008). *Guidelines for Occupational Therapy in Parkinson's Disease Rehabilitation*. Retrieved from Nijmegen, The Netherlands/Miami (FL), U.S.A.:

Styns, van Noorden, Moelants, & Leman. (2007). Walking on music. *Hum Mov Sci, 26*(5), 769-785. doi:10.1016/j.humov.2007.07.007

Švehlík, Zwick, Steinwender, Linhart, Schwingenschuh, Katschnig, . . . Enzinger. (2009). Gait Analysis in Patients With Parkinson's Disease Off Dopaminergic Therapy. *Archives of Physical Medicine and Rehabilitation, 90*(11), 1880-1886. doi:10.1016/j.apmr.2009.06.017

Tan, McGinley, Danoudis, Iansek, & Morris. (2011). Freezing of Gait and Activity Limitations in People With Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation, 92*(7), 1159-1165. doi:10.1016/j.apmr.2011.02.003

Thaut, & Abiru. (2010). Rhythmic Auditory Stimulation in Rehabilitation of Movement Disorders: A Review Of Current Research. *Music Perception: An Interdisciplinary Journal, 27*(4), 263-269. doi:10.1525/mp.2010.27.4.263

Thaut, Leins, Rice, Argstatter, Kenyon, McIntosh, . . . Fetter. (2007). Rhythmic auditory stimulation improves gait more than NDT/Bobath training in near-ambulatory patients early poststroke: a single-blind, randomized trial. *Neurorehabil Neural Repair, 21*(5), 455-459. doi:10.1177/1545968307300523

Thaut, McIntosh, Rice, Miller, Rathbun, & Brault. (1996). Rhythmic auditory stimulation in gait training for Parkinson’s disease patients. *Movement Disorders, 11*(2), 193-200. doi:10.1002/mds.870110213

Tomlinson, Patel, Meek, Clarke, Stowe, Shah, . . . et al. (2012). Physiotherapy versus placebo or no intervention in Parkinson's disease. *Cochrane Database of Systematic Reviews*(7). doi:10.1002/14651858.CD002817.pub2

Wall, De La Parra, Callaway, & Kreitzer. (2013). Differential Innervation of Direct- and Indirect-Pathway Striatal Projection Neurons. *Neuron, 79*(2), 347-360. doi:10.1016/j.neuron.2013.05.014

Widnell. (2005). Pathophysiology of motor fluctuations in Parkinson's disease. *Movement Disorders, 20*(S11), S17-S22. doi:10.1002/mds.20459

Wielinski, Erickson-Davis, Wichmann, Walde-Douglas, & Parashos. (2005). Falls and injuries resulting from falls among patients with Parkinson's disease and other parkinsonian syndromes. *Movement Disorders, 20*(4), 410-415. doi:10.1002/mds.20347

Willems, Nieuwboer, Chavret, Desloovere, Dom, Rochester, . . . Van Wegen. (2006). The use of rhythmic auditory cues to influence gait in patients with Parkinson's disease, the differential effect for freezers and non-freezers, an explorative study. *http://dx.doi.org/10.1080/09638280500386569, 28*, 721-728. doi:10.1080/09638280500386569

Witek, Clarke, Wallentin, Kringelbach, & Vuust. (2014). Syncopation, body-movement and pleasure in groove music. *PLoS ONE, 9*.

Wittwer, Webster, & Hill. (2013). Music and metronome cues produce different effects on gait spatiotemporal measures but not gait variability in healthy older adults. *Gait Posture, 37*(2), 219-222. doi:10.1016/j.gaitpost.2012.07.006

Yelnik. (2002). Functional anatomy of the basal ganglia. *Movement Disorders, 17*(S3), S15-S21. doi:10.1002/mds.10138

Yogev, Giladi, Peretz, Springer, Simon, & Hausdorff. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: which aspects of gait are attention demanding? *Eur J Neurosci, 22*. doi:10.1111/j.1460-9568.2005.04298.x

Zatorre. (2015). Musical pleasure and reward: mechanisms and dysfunction. *Ann N Y Acad Sci, 1337*, 202-211. doi:10.1111/nyas.12677

Zhu, Li, Ye, Jiang, Lei, & Shu. (2016). Sensory symptoms in Parkinson's disease: Clinical features, pathophysiology, and treatment. *Journal of Neuroscience Research, 94*(8), 685-692. doi:10.1002/jnr.23729

References

Aboutorabi, Arazpour, Bahramizadeh, Hutchins, & Fadayevatan. (2016). The effect of aging on gait parameters in able-bodied older subjects: a literature review. *Aging Clinical and Experimental Research, 28*(3), 393-405. doi:10.1007/s40520-015-0420-6

Al-Yahya, Dawes, Smith, Dennis, Howells, & Cockburn. (2011). Cognitive motor interference while walking: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews, 35*(3), 715-728. doi:10.1016/j.neubiorev.2010.08.008

Amboni, Barone, & Hausdorff. (2013). Cognitive contributions to gait and falls: evidence and implications. *Movement disorders : official journal of the Movement Disorder Society, 28*(11), 1520-1533. doi:10.1002/mds.25674

Aragon, & Kings. (2018). *Occupational Therapy for People with Parkinson's*. Retrieved from London, UK: www.rcot.co.uk

Balash, Peretz, Leibovich, Herman, Hausdorff, & Giladi. (2005). Falls in outpatients with Parkinson's disease. *Journal of Neurology, 252*(11), 1310-1315. doi:10.1007/s00415-005-0855-3

Benoit, Dalla Bella, Farrugia, Obrig, Mainka, & Kotz. (2014a). Musically cued gait-training improves both perceptual and motor timing in Parkinson's disease. *Front Hum Neurosci, 8*, 494. doi:10.3389/fnhum.2014.00494

Benoit, Dalla Bella, Farrugia, Obrig, Mainka, & Kotz. (2014b). Musically Cued Gait-Training Improves Both Perceptual and Motor Timing in Parkinson’s Disease. *Frontiers in Human Neuroscience, 8*(494). doi:10.3389/fnhum.2014.00494

Bieńkiewicz, & Craig. (2015). Parkinson's Is Time on Your Side? Evidence for Difficulties with Sensorimotor Synchronization. *Frontiers in Neurology, 6*, 249-249. doi:10.3389/fneur.2015.00249

Blin, Ferrandez, & Serratrice. (1990). Quantitative analysis of gait in Parkinson patients: increased variability of stride length. *J Neurol Sci, 98*(1), 91-97.

Brown, de Bruin, Doan, Suchowersky, & Hu. (2010). Obstacle crossing among people with Parkinson disease is influenced by concurrent music. *Journal of Rehabilitation Research and Development, 47*(3), 225-231.

Bryant, Rintala, Lai, & Protas. (2009). An evaluation of self-administration of auditory cueing to improve gait in people with Parkinson's disease. *Clinical Rehabilitation, 23*(12), 1078-1085. doi:10.1177/0269215509337465

Bugalho, Alves, & Miguel. (2013). Gait dysfunction in Parkinson's disease and normal pressure hydrocephalus: a comparative study. *Journal of Neural Transmission, 120*(8), 1201-1207. doi:10.1007/s00702-013-0975-3

Burger, Thompson, Luck, Saarikallio, & Toiviainen. (2014). Hunting for the beat in the body: on period and phase locking in music-induced movement. *Frontiers in Human Neuroscience, 8*(903). doi:10.3389/fnhum.2014.00903

Caetano, Lord, Schoene, Pelicioni, Sturnieks, & Menant. (2016). Age-related changes in gait adaptability in response to unpredictable obstacles and stepping targets. *Gait & Posture, 46*, 35-41. doi:https://doi.org/10.1016/j.gaitpost.2016.02.003

Callisaya, Beare, Phan, Blizzard, Thrift, Chen, & Srikanth. (2013). Brain structural change and gait decline: a longitudinal population-based study. *J Am Geriatr Soc, 61*(7), 1074-1079. doi:10.1111/jgs.12331

Cameron, Bentley, & Grahn. (2015). Cross-cultural influences on rhythm processing: reproduction, discrimination, and beat tapping. *Frontiers in psychology, 6*(366). doi:10.3389/fpsyg.2015.00366

Cameron, Pickett, Earhart, & Grahn. (2016). The Effect of Dopaminergic Medication on Beat-Based Auditory Timing in Parkinson's Disease. *Frontiers in Neurology, 7*(19). doi:10.3389/fneur.2016.00019

Cameron, Stewart, Pearce, Grube, & Muggleton. (2012). Modulation of Motor Excitability by Metricality of Tone Sequences. *Psychomusicology: Music, Mind, and Brain, 22*(2), 122-128. doi:10.1037/a0031229

Canadian Institute for Health Information. (2007). *The Burden of Neurological Diseases, Disorders and Injuries in Canada* Ottawa: CIHI.

Cha, Kim, & Chung. (2014). Immediate Effects of Rhythmic Auditory Stimulation with Tempo Changes on Gait in Stroke Patients. *Journal of Physical Therapy Science, 26*(4), 479-482. doi:10.1589/jpts.26.479

Chen, Penhune, & Zatorre. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cereb Cortex, 18*(12), 2844-2854. doi:10.1093/cercor/bhn042

Cochen De Cock, Dotov, Ihalainen, Bégel, Galtier, Lebrun, . . . Dalla Bella. (2018). Rhythmic abilities and musical training in Parkinson's disease: do they help? *NPJ Parkinson's disease, 4*, 8-8. doi:10.1038/s41531-018-0043-7

Dalla Bella, Benoit, Farrugia, Keller, Obrig, Mainka, & Kotz. (2017). Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. *Sci Rep, 7*, 42005. doi:10.1038/srep42005

Dalla Bella, Dotov, Bardy, & Cock Valérie. (2018). Individualization of music-based rhythmic auditory cueing in Parkinson's disease. *Annals of the New York Academy of Sciences, 0*(0). doi:10.1111/nyas.13859

Dalla Bella, Sowi, & ski. (2015). Uncovering Beat Deafness: Detecting Rhythm Disorders with Synchronized Finger Tapping and Perceptual Timing Tasks. *Journal of Visualized Experiments*(97), e51761. doi:doi:10.3791/51761

de Bruin, Doan, Turnbull, Suchowersky, Bonfield, Hu, & Brown. (2010). Walking with Music Is a Safe and Viable Tool for Gait Training in Parkinson's Disease: The Effect of a 13-Week Feasibility Study on Single and Dual Task Walking. *Parkinson's Disease, 2010*, 1-9. doi:10.4061/2010/483530

de Bruin, Kempster, Doucette, Doan, Hu, & Brown. (2015). The effects of music salience on the gait performance of young adults. *Journal of Music Therapy, 52*(3), 394-419. doi:10.1093/jmt/thv009

de Lau, & Breteler. (2006). Epidemiology of Parkinson's disease. *Lancet Neurology, 5*(6), 525-535. doi:10.1016/S1474-4422(06)70471-9

Deane, Ellis-Hill, Dekker, Davies, & Clarke. (2003). A Delphi Survey of Best Practice Occupational Therapy for Parkinson's Disease in the United Kingdom. *British Journal of Occupational Therapy, 66*(6), 247-254. doi:10.1177/030802260306600603

DeLong. (1990). Primate models of movement disorders of basal ganglia origin. *Trends in Neurosciences, 13*(7), 281-285.

Donoghue, Cronin, Savva, O'Regan, & Kenny. (2013). Effects of fear of falling and activity restriction on normal and dual task walking in community dwelling older adults. *Gait & Posture, 38*(1), 120-124. doi:https://doi.org/10.1016/j.gaitpost.2012.10.023

Dotov, Bayard, Cochen de Cock, Geny, Driss, Garrigue, . . . Dalla Bella. (2017). Biologically-variable rhythmic auditory cues are superior to isochronous cues in fostering natural gait variability in Parkinson's disease. *Gait Posture, 51*, 64-69. doi:10.1016/j.gaitpost.2016.09.020

Dunlap, Perera, VanSwearingen, Wert, & Brach. (2012). Transitioning to a narrow path: The impact of fear of falling in older adults. *Gait & Posture, 35*(1), 92-95. doi:https://doi.org/10.1016/j.gaitpost.2011.08.013

Ebersbach, Moreau, Gandor, Defebvre, & Devos. (2013). Clinical syndromes: Parkinsonian gait. *Movement Disorders, 28*(11), 1552-1559. doi:10.1002/mds.25675

Ellis, Cavanaugh, Earhart, Ford, Foreman, & Dibble. (2011). Which measures of physical function and motor impairment best predict quality of life in Parkinson's disease? *Parkinsonism and Related Disorders, 17*(9), 693-697. doi:10.1016/j.parkreldis.2011.07.004

Fahn. (1999). Parkinson disease, the effect of levodopa, and the elldopa trial. *Archives of Neurology, 56*(5), 529-535. doi:10.1001/archneur.56.5.529

Fahn, Oakes, Shoulson, Kieburtz, Rudolph, Lang, . . . Parkinson Study. (2004). Levodopa and the Progression of Parkinson's Disease. *The New England Journal of Medicine, 351*(24), 2498-2508.

Farrer. (2006). Genetics of Parkinson disease: paradigm shifts and future prospects. *Nature Reviews. Genetics, 7*(4), 306-318. doi:http://dx.doi.org/10.1038/nrg1831

Fox, Katzenschlager, Lim, Barton, de Bie, Seppi, . . . Sampaio. (2018). International Parkinson and movement disorder society evidence-based medicine review: Update on treatments for the motor symptoms of Parkinson's disease. *Movement Disorders, 33*(8), 1248-1266. doi:10.1002/mds.27372

Gabell, & Nayak. (1984). The effect of age on variability in gait. *J Gerontol, 39*(6), 662-666.

Ghai, Ghai, & Effenberg. (2018). Effect of Rhythmic Auditory Cueing on Aging Gait: A Systematic Review and Meta-Analysis. *Aging and disease, 9*(5), 901-923. doi:10.14336/AD.2017.1031

Ghai, Ghai, Schmitz, & Effenberg. (2018). Effect of rhythmic auditory cueing on parkinsonian gait: A systematic review and meta-analysis. *Sci Rep, 8*(1), 506. doi:10.1038/s41598-017-16232-5

Giladi, Shabtai, Rozenberg, & Shabtai. (2001). Gait festination in Parkinson's disease. *Parkinsonism and Related Disorders, 7*(2), 135-138. doi:10.1016/S1353-8020(00)00030-4

Grafton. (2004). Contributions of functional imaging to understanding parkinsonian symptoms. *Current Opinion in Neurobiology, 14*(6), 715-719. doi:10.1016/j.conb.2004.10.010

Grahn, & Brett. (2009). Impairment of beat-based rhythm discrimination in Parkinson's disease. *Cortex, 45*(1), 54-61. doi:10.1016/j.cortex.2008.01.005

Grahn, & Rowe. (2009). Feeling the beat: premotor and striatal interactions in musicians and nonmusicians during beat perception. *J Neurosci, 29*(23), 7540-7548. doi:10.1523/jneurosci.2018-08.2009

Grahn, & Schuit. (2012). Individual Differences in Rhythmic Ability: Behavioral and Neuroimaging Investigations. *Psychomusicology, 22*(2), 105-121. doi:10.1016/S1364-6613(00)01538-2

Gupta. (2002). Anatomy and physiology of the Basal Ganglia. *Psychiatric Annals, 32*(4), 230-232.

Hak, Houdijk, Beek, & van Dieën. (2013). Steps to take to enhance gait stability: the effect of stride frequency, stride length, and walking speed on local dynamic stability and margins of stability. *PLoS ONE, 8*(12), e82842-e82842. doi:10.1371/journal.pone.0082842

Hass, Chris, Mark, Mariana, & Elizabeth. (2014). Defining the Clinically Meaningful Difference in Gait Speed in Persons With Parkinson Disease. *Journal of neurologic physical therapy, 38*(4).

Hausdorff, Cudkowicz, Firtion, Wei, & Goldberger. (1998). Gait variability and basal ganglia disorders: stride-to-stride variations of gait cycle timing in Parkinson's disease and Huntington's disease. *Mov Disord, 13*(3), 428-437. doi:10.1002/mds.870130310

Hausdorff, Edelberg, Mitchell, Goldberger, & Wei. (1997). Increased gait unsteadiness in community-dwelling elderly fallers. *Arch Phys Med Rehabil, 78*. doi:10.1016/s0003-9993(97)90034-4

Hausdorff, Rios, & Edelberg. (2001). Gait variability and fall risk in community-living older adults: a 1-year prospective study. *Arch Phys Med Rehabil, 82*. doi:10.1053/apmr.2001.24893

Health Canada, & Parkinson Society Canada. (2003). *Parkinson's Disease: Social and Economic Impact*. Toronto: PSC.

Hollman, Childs, McNeil, Mueller, Quilter, & Youdas. (2010). Number of strides required for reliable measurements of pace, rhythm and variability parameters of gait during normal and dual task walking in older individuals. *Gait & Posture, 32*(1), 23-28. doi:https://doi.org/10.1016/j.gaitpost.2010.02.017

Honma, Kuroda, Futamura, Shiromaru, & Kawamura. (2016). Dysfunctional counting of mental time in Parkinson’s disease. *Sci Rep, 6*, 25421. doi:10.1038/srep25421

https://www.nature.com/articles/srep25421#supplementary-information

Hove, Suzuki, Uchitomi, Orimo, & Miyake. (2012). Interactive Rhythmic Auditory Stimulation Reinstates Natural 1/<italic>f</italic> Timing in Gait of Parkinson's Patients. *PLoS ONE, 7*(3), e32600. doi:10.1371/journal.pone.0032600

Howe, Lovgreen, Cody, Ashton, & Oldham. (2003). Auditory cues can modify the gait of persons with early-stage Parkinson's disease: a method for enhancing parkinsonian walking performance? *Clin Rehabil, 17*(4), 363-367. doi:10.1191/0269215503cr621oa

Hung, & Schwarzschild. (2014). Treatment of Parkinson’s Disease: What’s in the Non-dopaminergic Pipeline? *Neurotherapeutics, 11*(1), 34-46. doi:10.1007/s13311-013-0239-9

Inzelberg, Schechtman, & Paleacu. (2002). Onset age of Parkinson disease. *American Journal of Medical Genetics, 111*(4), 459-460. doi:10.1002/ajmg.10586

Janata, Tomic, & Haberman. (2012). Sensorimotor coupling in music and the psychology of the groove. *Journal of Experimental Psychology: General, 141*(1), 54-75. doi:http://dx.doi.org/10.1037/a0024208

Jankovic. (2008). Parkinson's disease: clinical features and diagnosis. *Journal of Neurology, Neurosurgery & Psychiatry, 79*(4), 368-376. doi:10.1136/jnnp.2007.131045

Jenkins, Almeida, Spaulding, van Oostveen, Holmes, Johnson, & Perry. (2009). Plantar cutaneous sensory stimulation improves single-limb support time, and EMG activation patterns among individuals with Parkinson's disease. *Parkinsonism and Related Disorders, 15*(9), 697-702. doi:10.1016/j.parkreldis.2009.04.004

Keus, Bloem, Hendriks, Bredero-Cohen, & Munneke. (2007). Evidence-based analysis of physical therapy in Parkinson's disease with recommendations for practice and research. *Movement Disorders, 22*(4), 451-460. doi:10.1002/mds.21244

Kim, Allen, Canning, & Fung. (2013). Postural Instability in Patients with Parkinson's Disease: Epidemiology, Pathophysiology and Management. *CNS Drugs, 27*(2), 97-112. doi:10.1007/s40263-012-0012-3

Kimmeskamp, & Hennig. (2001). Heel to toe motion characteristics in Parkinson patients during free walking. *Clin Biomech (Bristol, Avon), 16*(9), 806-812.

Kotz, Schwartze, & Schmidt-Kassow. (2009). Non-motor basal ganglia functions: a review and proposal for a model of sensory predictability in auditory language perception. *Cortex, 45*(8), 982-990. doi:10.1016/j.cortex.2009.02.010

Kovacs. (2005). Age-Related Changes in Gait and Obstacle Avoidance Capabilities in Older Adults: A Review. *Journal of Applied Gerontology, 24*(1), 21-34. doi:10.1177/0733464804271279

Kung, Chen, Zatorre, & Penhune. (2013). Interacting cortical and basal ganglia networks underlying finding and tapping to the musical beat. *J Cogn Neurosci, 25*(3), 401-420. doi:10.1162/jocn_a_00325

LabVIEW. Austin, TX: National Instruments.

Lai, Marion, Teschke, & Tsui. (2002). Occupational and environmental risk factors for Parkinson's disease. *Parkinsonism and Related Disorders, 8*(5), 297-309. doi:10.1016/S1353-8020(01)00054-2

Laughton, Slavin, Katdare, Nolan, Bean, Kerrigan, . . . Collins. (2003). Aging, muscle activity, and balance control: physiologic changes associated with balance

impairment. *Gait & Posture, 18*(2), 101-108. doi:https://doi.org/10.1016/S0966-6362(02)00200-X

Launay, Grube, & Stewart. (2014). Dysrhythmia: a specific congenital rhythm perception deficit. *Front Psychol, 5*, 18. doi:10.3389/fpsyg.2014.00018

Lee. (2017). Effects of single and dual tasks during walking on spatiotemporal gait parameters of community-dwelling older. *Journal of Physical Therapy Science, 29*(10), 1874-1877. doi:10.1589/jpts.29.1874

Leow, Parrott, & Grahn. (2014). Individual differences in beat perception affect gait responses to low- and high-groove music. *Frontiers in Human Neuroscience, 8*. doi:10.3389/fnhum.2014.00811

Leow, Rinchon, & Grahn. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *Annals of the New York Academy of Sciences, 1337*(1), 53-61. doi:10.1111/nyas.12658

Leow, Waclawik, & Grahn. (2018). The role of attention and intention in synchronization to music: effects on gait. *Experimental Brain Research, 236*(1), 99-115. doi:10.1007/s00221-017-5110-5

Lim, van Wegen, de Goede, Deutekom, Nieuwboer, Willems, . . . Kwakkel. (2005). Effects of external rhythmical cueing on gait in patients with Parkinson's disease: a systematic review. *Clinical Rehabilitation, 19*(7), 695-713. doi:10.1191/0269215505cr906oa

Limousin, & Martinez-Torres. (2008). Deep brain stimulation for Parkinson’s disease. *Neurotherapeutics, 5*(2), 309-319. doi:10.1016/j.nurt.2008.01.006

Macphee, & Stewart. (2012). Parkinson's disease – pathology, aetiology and diagnosis. *Reviews in Clinical Gerontology, 22*(3), 165-178. doi:10.1017/S095925981200007X

Marr. (1991). The Experience Of Living With Parkinson's Disease. *Journal of Neuroscience Nursing, 23*(5), 325-329.

Matthews, Witek, Heggli, Penhune, & Vuust. (2019). The sensation of groove is affected by the interaction of rhythmic and harmonic complexity. *PLoS ONE, 14*, e0204539.

Maylor, & Wing. (1996). Age differences in postural stability are increased by additional cognitive demands. *J Gerontol B Psychol Sci Soc Sci, 51*. doi:10.1093/geronb/51B.3.P143

Mazzoni, Hristova, & Krakauer. (2007). Why Don't We Move Faster? Parkinson's Disease, Movement Vigor, and Implicit Motivation. *The Journal of Neuroscience, 27*(27), 7105. doi:10.1523/JNEUROSCI.0264-07.2007

McAuley, Daly, & Curtis. (2009). A preliminary investigation of a novel design of visual cue glasses that aid gait in Parkinson's disease. *Clinical Rehabilitation, 23*(8), 687-695. doi:10.1177/0269215509104170

McIntosh, Brown, Rice, & Thaut. (1997). Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *Journal of Neurology, Neurosurgery and Psychiatry, 62*, 22-26. doi:10.1136/jnnp.62.1.22

Mendonça, Oliveira, Fontes, & Santos. (2014). The effect of instruction to synchronize over step frequency while walking with auditory cues on a treadmill. *Hum Mov Sci, 33*, 33-42. doi:10.1016/j.humov.2013.11.006

Merchant, Luciana, Hooper, Majestic, & Tuite. (2008). Interval timing and Parkinson's disease: heterogeneity in temporal performance. *Exp Brain Res, 184*(2), 233-248. doi:10.1007/s00221-007-1097-7

Miller, Kwak, Bohnen, Müller, Dayalu, & Seidler. (2013). The pattern of striatal dopaminergic denervation explains sensorimotor synchronization accuracy in Parkinson's disease. *Behavioural Brain Research, 257*, 100-110. doi:https://doi.org/10.1016/j.bbr.2013.09.032

Moore, Peretz, & Giladi. (2007). Freezing of gait affects quality of life of peoples with Parkinson’s disease beyond its relationships with mobility and gait. *Movement Disorders, 22*(15), 2192-2195. doi:10.1002/mds.21659

Morris. (2000). Movement Disorders in People With Parkinson Disease: A Model for Physical Therapy. *Physical Therapy, 80*(6), 578-597. doi:10.1093/ptj/80.6.578

Morris, Huxham, McGinley, Dodd, & Iansek. (2001). The biomechanics and motor control of gait in Parkinson disease. *Clinical Biomechanics, 16*(6), 459-470. doi:10.1016/S0268-0033(01)00035-3

Morris, Iansek, & Galna. (2008). Gait festination and freezing in Parkinson's disease: Pathogenesis and rehabilitation. *Movement Disorders, 23*(S2), S451-S460. doi:10.1002/mds.21974

Morris, Iansek, Matyas, & Summers. (1996). Stride length regulation in Parkinson's disease. Normalization strategies and underlying mechanisms. *Brain, 119*(2), 551-568.

Morris, Martin, & Schenkman. (2010). Striding Out With Parkinson Disease: Evidence-Based Physical Therapy for Gait Disorders. *Physical Therapy, 90*(2), 280-288. doi:10.2522/ptj.20090091

Mullensiefen, Gingras, Musil, & Stewart. (2014). The Musicality of Non-Musicians: An Index for Assessing Musical Sophistication in the General Population. *PLoS ONE, 9*, e89642.

Müllensiefen, Gingras, Stewart, & Musil. (2014). *The Goldsmiths Musical Sophistication Index (Gold-MSI): Technical Report and Documentation v1.0*. Retrieved from London:

Nieuwboer, Kwakkel, Rochester, Jones, van Wegen, Willems, . . . Lim. (2007). Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. *Journal of Neurology, Neurosurgery & Psychiatry, 78*(2), 134-140. doi:10.1136/jnnp.200X.097923

Niv, Joel, & Dayan. (2006). A normative perspective on motivation. *Trends in Cognitive Sciences, 10*(8), 375-381. doi:10.1016/j.tics.2006.06.010

Nombela, Hughes, Owen, & Grahn. (2013). Into the groove: Can rhythm influence Parkinson's disease? *Neuroscience and Biobehavioral Reviews, 37*(10), 2564-2570. doi:10.1016/j.neubiorev.2013.08.003

Nonnekes, Giladi, Guha, & Fietzek. (2019). Gait festination in parkinsonism: introduction of two phenotypes. *Journal of Neurology, 266*(2), 426-430. doi:10.1007/s00415-018-9146-7

O'Shea, Morris, & Iansek. (2002). Dual task interference during gait in people with Parkinson disease: Effects of motor versus cognitive secondary tasks. *Physical Therapy, 82*(9), 888-897.

Pastor, Artieda, Jahanshahi, & Obeso. (1992). Time estimation and reproduction is abnormal in Parkinson's disease. *Brain, 115 Pt 1*, 211-225.

Patel, Jankovic, & Hallett. (2014). Sensory aspects of movement disorders. *Lancet Neurology, 13*(1), 100-112. doi:10.1016/S1474-4422(13)70213-8

Patterson, Wong, Knorr, & Grahn. (2018). Rhythm Perception and Production Abilities and Their Relationship to Gait After Stroke. *Arch Phys Med Rehabil, 99*(5), 945-951. doi:10.1016/j.apmr.2018.01.009

Perry, Carville, Smith, Rutherford, & Newham. (2007). Strength, power output and symmetry of leg muscles: effect of age and history of falling. *European Journal of Applied Physiology, 100*(5), 553-561. doi:10.1007/s00421-006-0247-0

Phillips-Silver, Toiviainen, Gosselin, Piché, Nozaradan, Palmer, & Peretz. (2011). Born to dance but beat deaf: A new form of congenital amusia. *Neuropsychologia, 49*(5), 961-969. doi:10.1016/j.neuropsychologia.2011.02.002

Povel, & Essens. (1985). Perception of temporal patterns. [doi:10.2307/40285311]. US: University of California Press.

Priest, Salamon, & Hollman. (2008). Age-related differences in dual task walking: a cross sectional study. *Journal of NeuroEngineering and Rehabilitation, 5*(1), 29. doi:10.1186/1743-0003-5-29

Qualtrics. (2018). Provo, Utah, USA. Retrieved from https://www.qualtrics.com

Ready, McGarry, Rinchon, Holmes, & Grahn. (2019). Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait & Posture, 68*, 555-561. doi:https://doi.org/10.1016/j.gaitpost.2018.12.038

Rennie, Löfgren, Moe-Nilssen, Opheim, Dietrichs, & Franzén. (2018). The reliability of gait variability measures for individuals with Parkinson's disease and healthy older adults – The effect of gait speed. *Gait & Posture, 62*, 505-509. doi:https://doi.org/10.1016/j.gaitpost.2018.04.011

Roberts. (2017). *Comparing the influence of music enjoyment and beat perception ability on spatiotemporal gait parameters among healthy young and older adults.* (Master of Science), University of Western Ontario, Electronic Thesis and Dissertation Repository. Retrieved from https://ir.lib.uwo.ca/etd/4893 (4893)

Rocha, Porfírio, Ferraz, & Trevisani. (2014). Effects of external cues on gait parameters of Parkinson's disease patients: A systematic review. *Clinical Neurology and Neurosurgery, 124*, 127-134. doi:10.1016/j.clineuro.2014.06.026

Rochester, Hetherington, Jones, Nieuwboer, Willems, Kwakkel, & Van Wegen. (2005). The Effect of External Rhythmic Cues (Auditory and Visual) on Walking During a Functional Task in Homes of People With Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation, 86*(5), 999-1006. doi:10.1016/j.apmr.2004.10.040

Ruiz, Catalán, & Carril. (2011). Initial Motor Symptoms of Parkinson Disease. *The Neurologist, 17*, S18-S20. doi:10.1097/NRL.0b013e31823966b4

Schaafsma, Giladi, Balash, Bartels, Gurevich, & Hausdorff. (2003). Gait dynamics in Parkinson's disease: relationship to Parkinsonian features, falls and response to levodopa. *Journal of the Neurological Sciences, 212*(1-2), 47-53. doi:10.1016/S0022-510X(03)00104-7

Schapira. (2009). Neurobiology and treatment of Parkinson's disease. *Trends in Pharmacological Sciences, 30*(1), 41-47. doi:10.1016/j.tips.2008.10.005

Schrag, Jahanshahi, & Quinn. (2000). How does Parkinson's disease affect quality of life? A comparison with quality of life in the general population. *Movement Disorders, 15*(6), 1112-1118. doi:10.1002/1531-8257(200011)15:6<1112::AID-MDS1008>3.0.CO;2-A

Sethi. (2008). Levodopa unresponsive symptoms in Parkinson disease. *Movement Disorders, 23*(S3), S521-S533. doi:10.1002/mds.22049

Shahraki, Sohrabi, Taheri Torbati, Nikkhah, & NaeimiKia. (2017). Effect of rhythmic auditory stimulation on gait kinematic parameters of patients with multiple sclerosis. *J Med Life, 10*(1), 33-37.

Shen, X., Wong-Yu, I., & Mak, M. (2016). Effects of exercise on falls, balance, and gait ability in parkinson's disease: A meta-analysis. *Neurorehabilitation and Neural Repair, 30*(6), 512-527. doi:10.1177/1545968315613447

Shulman, De Jager, & Feany. (2011). Parkinson's Disease: Genetics and Pathogenesis. *Annual Review of Pathology: Mechanisms of Disease, 6*, 193-222. doi:10.1146/annurev-pathol-011110-130242

Skodda, Flasskamp, & Schlegel. (2010). Instability of syllable repetition as a model for impaired motor processing: is Parkinson's disease a "rhythm disorder"? *J Neural Transm (Vienna), 117*(5), 605-612. doi:10.1007/s00702-010-0390-y

Smith, Harper, Gittings, & Abernethy. (2007). The effect of Parkinson's disease on time estimation as a function of stimulus duration range and modality. *Brain Cogn, 64*(2), 130-143. doi:10.1016/j.bandc.2007.01.005

Sofuwa, Nieuwboer, Desloovere, Willems, Chavret, & Jonkers. (2005). Quantitative Gait Analysis in Parkinson's Disease: Comparison With a Healthy Control Group. *Archives of Physical Medicine and Rehabilitation, 86*(5), 1007-1013. doi:10.1016/j.apmr.2004.08.012

Son, & Kim. (2015). Kinematic analysis of arm and trunk movements in the gait of Parkinson's disease patients based on external signals. *Journal of Physical Therapy Science, 27*(12), 3783-3786. doi:10.1589/jpts.27.3783

Soundy, Stubbs, & Roskell. (2013). *The Experience of Parkinson's Disease: A Systematic Review and Meta-Ethnography* (Vol. accepted manusript).

Spaulding, Barber, Colby, Cormack, Mick, & Jenkins. (2013). Cueing and Gait Improvement Among People With Parkinson's Disease: A Meta-Analysis. *Archives of Physical Medicine and Rehabilitation, 94*(3), 562-570. doi:10.1016/j.apmr.2012.10.026

Stupacher, Hove, & Janata. (2016). Audio Features Underlying Perceived Groove and Sensorimotor Synchronization in Music. *Music Perception: An Interdisciplinary Journal, 33*(5), 571. doi:10.1525/mp.2016.33.5.571

Stupacher, Hove, Novembre, Schütz-Bosbach, & Keller. (2013). Musical groove modulates motor cortex excitability: A TMS investigation. *Brain and Cognition, 82*(2), 127-136. doi:https://doi.org/10.1016/j.bandc.2013.03.003

Sturkenboom, Thijssen, Gons-van Elsacker, Jansen, Maasdam, Schulten, . . . Munneke. (2008). *Guidelines for Occupational Therapy in Parkinson's Disease Rehabilitation*. Retrieved from Nijmegen, The Netherlands/Miami (FL), U.S.A.:

Styns, van Noorden, Moelants, & Leman. (2007). Walking on music. *Hum Mov Sci, 26*(5), 769-785. doi:10.1016/j.humov.2007.07.007

Švehlík, Zwick, Steinwender, Linhart, Schwingenschuh, Katschnig, . . . Enzinger. (2009). Gait Analysis in Patients With Parkinson's Disease Off Dopaminergic Therapy. *Archives of Physical Medicine and Rehabilitation, 90*(11), 1880-1886. doi:10.1016/j.apmr.2009.06.017

Tan, McGinley, Danoudis, Iansek, & Morris. (2011). Freezing of Gait and Activity Limitations in People With Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation, 92*(7), 1159-1165. doi:10.1016/j.apmr.2011.02.003

Thaut, & Abiru. (2010). Rhythmic Auditory Stimulation in Rehabilitation of Movement Disorders: A Review Of Current Research. *Music Perception: An Interdisciplinary Journal, 27*(4), 263-269. doi:10.1525/mp.2010.27.4.263

Thaut, Leins, Rice, Argstatter, Kenyon, McIntosh, . . . Fetter. (2007). Rhythmic auditory stimulation improves gait more than NDT/Bobath training in near-ambulatory patients early poststroke: a single-blind, randomized trial. *Neurorehabil Neural Repair, 21*(5), 455-459. doi:10.1177/1545968307300523

Thaut, McIntosh, Rice, Miller, Rathbun, & Brault. (1996). Rhythmic auditory stimulation in gait training for Parkinson’s disease patients. *Movement Disorders, 11*(2), 193-200. doi:10.1002/mds.870110213

Tomlinson, Patel, Meek, Clarke, Stowe, Shah, . . . et al. (2012). Physiotherapy versus placebo or no intervention in Parkinson's disease. *Cochrane Database of Systematic Reviews*(7). doi:10.1002/14651858.CD002817.pub2

Wall, De La Parra, Callaway, & Kreitzer. (2013). Differential Innervation of Direct- and Indirect-Pathway Striatal Projection Neurons. *Neuron, 79*(2), 347-360. doi:10.1016/j.neuron.2013.05.014

Widnell. (2005). Pathophysiology of motor fluctuations in Parkinson’s disease. *Movement Disorders, 20*(S11), S17-S22. doi:10.1002/mds.20459

Wielinski, Erickson-Davis, Wichmann, Walde-Douglas, & Parashos. (2005). Falls and injuries resulting from falls among patients with Parkinson’s disease and other parkinsonian syndromes. *Movement Disorders, 20*(4), 410-415. doi:10.1002/mds.20347

Willems, Nieuwboer, Chavret, Desloovere, Dom, Rochester, . . . Van Wegen. (2006). The use of rhythmic auditory cues to influence gait in patients with Parkinson's

disease, the differential effect for freezers and non-freezers, an explorative study. *http://dx.doi.org/10.1080/09638280500386569, 28*, 721-728. doi:10.1080/09638280500386569

Witek, Clarke, Wallentin, Kringelbach, & Vuust. (2014). Syncopation, body-movement and pleasure in groove music. *PLoS ONE, 9*.

Wittwer, Webster, & Hill. (2013). Music and metronome cues produce different effects on gait spatiotemporal measures but not gait variability in healthy older adults. *Gait Posture, 37*(2), 219-222. doi:10.1016/j.gaitpost.2012.07.006

Yelnik. (2002). Functional anatomy of the basal ganglia. *Movement Disorders, 17*(S3), S15-S21. doi:10.1002/mds.10138

Yogev, Giladi, Peretz, Springer, Simon, & Hausdorff. (2005). Dual tasking, gait rhythmicity, and Parkinson's disease: which aspects of gait are attention demanding? *Eur J Neurosci, 22*. doi:10.1111/j.1460-9568.2005.04298.x

Zatorre. (2015). Musical pleasure and reward: mechanisms and dysfunction. *Ann N Y Acad Sci, 1337*, 202-211. doi:10.1111/nyas.12677

Zhu, Li, Ye, Jiang, Lei, & Shu. (2016). Sensory symptoms in Parkinson's disease: Clinical features, pathophysiology, and treatment. *Journal of Neuroscience Research, 94*(8), 685-692. doi:10.1002/jnr.23729

Appendices

Appendix A: Demographic Questionnaire (Section one of the demographic questionnaire provided to participants, completed prior to cued gait trials).

Start of Block: Default Question Block

Q1 FOR THE EXPERIMENTER: Enter the study participant number (e.g., FREE-001).

_____

Q2 What is your gender?

- Male (1)
- Female (2)
- Other (3)

Q3 What is your age?

_____

Q4 Do you take any psychotropic drugs, either recreationally or medicinally?

Psychotropic drugs: ones that can alter chemical levels in the brain which impact mood and behavior (e.g., marijuana, anti-depressants, muscle relaxants)

- ○ Yes (1)
- ○ No (2)

Q5 If yes, please describe:

_____

Q6 Do you have any psychiatric or neurological conditions?

- ○ Yes (1)
- ○ No (2)

Q7 If yes, please describe:

_____

Q8 How many years of education do you have (starting at Grade 1 and including any higher education)?

_____

Q9 What is your dominant hand?

- ○ Right (1)
- ○ Left (2)
- ○ Ambidextrous (3)

Q10 Do you have normal hearing?

- ○ Yes (1)
- ○ No (2)

Q11 If you indicated that you do not have normal hearing, please elaborate:

_____

Q12 Have you experienced any difficulties walking in the past year?

- ○ Yes (1)
- ○ No (2)

Q13 If you indicated yes to the question above, please elaborate:

_____

Page Break

Q14 You have completed the first part of the survey. Please DO NOT continue to the next part of the survey OR close this window.

You may inform the experimenter that you're ready to continue with the rest of the study.

Page Break

Appendix B: Demographic Questionnaire (Section two of the demographic questionnaire provided to participants regarding dance and music training, completed after cued gait trials).

Q15 Do you have any formal music training (for either voice or an instrument)?

- Yes (1)
- No (2)

Q15 Do you have any formal music training (for either voice or an instrument)?

- Yes (1)
- No (2)

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q16 Which instrument(s)?

_____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q17 Please list the age you starting playing each instrument (or singing) and the age you stopped playing (if you no longer play)

_____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q18 Please list the number of years of training you have for each instrument you listed.

_____

_____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q19 What type of training did you received?

- ☐ School/Band/Choir (1)
- ☐ Private Lessons (2)
- ☐ Church (3)
- ☐ Friends/Family (4)
- ☐ Self Taught (5)
- ☐ Other (6)

Display This Question:

If What type of training did you received? = Other

Q20 You indicated "Other" - Please describe your training

_____

Display This Question:

If Do you have any formal music training (for either voice or an instrument)? = Yes

Q21 When was the last time you played?

_____

Q22 Do you identify as a musician?

- Yes (1)
- No (2)

Page Break

Q23 Do you have any formal dance training?

- Yes (1)
- No (2)

Display This Question:

If Do you have any formal dance training? = Yes

Q24 What style(s) of dance?

_____

Display This Question:

If Do you have any formal dance training? = Yes

Q25 Please list the age at which you started each style and the age you stopped (if you no longer dance).

_____

Display This Question:

If Do you have any formal dance training? = Yes

Q26 Please list the number of years of training you have for each style.

_____

Display This Question:

If Do you have any formal dance training? = Yes

Q27 What type of training did you receive?

- ☐ School (1)
- ☐ Private/Group lessons (2)
- ☐ Friends/Family (3)
- ☐ Self-Taught (4)
- ☐ Other (5)

Display This Question:

If What type of training did you receive? = Other

Q28 You indicated "other" - please describe your training.

_____

Display This Question:

If Do you have any formal dance training? = Yes

Q29 When was the last time you danced?

_____

Q36 Do you identify as a dancer?

- ○ Yes (1)
- ○ No (2)

Page Break

Appendix C: Ethics approval, letter of information, and consent form for Study 1 (Chapter 3).

Western Research

Research Ethics

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

Date: March 16, 2016 (There was a lapse in approval from March 2, 2016 to March 16, 2016)
Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,

NMREB File Number: 104487
Study Title: Walking at different speeds

NMREB Renewal Due Date & NMREB Expiry Date:
Renewal Due -2017/02/28
Expiry Date -2017/03/01

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.

[redacted]

Ethics Officer to Contact for Further Information: [redacted]

This is an official document. Please retain a copy for your files.

Western University, Research, [redacted]
London, ON, Canada N6G 1G9 [redacted] www.uwo.ca/research/ethics

Western Research

Research Ethics

Western University Non-Medical Research Ethics Board
NMREB Amendment Approval Notice

Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,

NMREB File Number: 104487
Study Title: Walking at different speeds
Sponsor:

NMREB Revision Approval Date: March 23, 2015
NMREB Expiry Date: March 01, 2016

Documents Approved and/or Received for Information:

Document Name	Comments	Version Date
Revised Western University Protocol		

The Western University Non-Medical Science Research Ethics Board (NMREB) has reviewed and approved the amendment to the above named study, as of the NMREB Amendment Approval Date noted above.

NMREB approval for this study remains valid until the NMREB Expiry Date noted above, conditional to timely submission and acceptance of NMREB Continuing Ethics Review.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), 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.

[redacted]

Ethics Officer to Contact for Further Information

[redacted]	[redacted]	[redacted]	[redacted]

This is an official document. Please retain the original in your files.

Western
The Brain and Mind Institute

Project Title: Walking at different speeds
Principal Investigator: Dr. Jessica Grahn, Brain and Mind Institute, The University of Western Ontario. Email: [redacted]

Letter of Information

1. **Invitation to Participate**

   You have been invited to participate in this study conducted by Dr Li-Ann Leow and Dr. Jessica Grahn.

2. **Purpose of the Letter**

   The purpose of this letter is to provide you with information required for you to make an informed decision regarding participation in this research.

3. **Purpose of this Study**
   This research project aims to examine a demographically diverse population to better understand music preferences and individual differences in beat perception in the general population.

4. **Inclusion Criteria**
   Individuals who have normal hearing and who do not have any neurological problems are eligible to participate in this study.

5. **Exclusion Criteria**

   Individuals who are have hearing and/ or neurological problems are not eligible to participate in this study.

6. **Study Procedures**

   If you agree to participate, you will be asked to walk on a pressure sensor walkway with and without some auditory stimuli. You will also be asked to listen to and make judgments about and respond to some auditory stimuli. You may also be asked some questions about your musical experience. You will receive written feedback at the end of the test session about the study and you will have a chance to ask questions about the study. It is anticipated that the entire study will take approximately 1.5 hours, over 1 session.

7. **Possible Risks and Harms**

   There are no known or anticipated risks or discomforts associated with participating in this study.

Western
The Brain and Mind Institute

8. Possible Benefits

You may not directly benefit from participating in this study but information gathered may provide benefits to society as a whole which include advancing knowledge about how humans move in response to different auditory stimuli.

9. Compensation

The study will take approximately 1.5 hours to complete. If you are a first year psychology student recruited from the SONA participant pool at the University of Western Ontario, you will receive 1.5 credit points for your participation. If you were not recruited from the SONA participant pool, you will receive $10 as compensation. If you do not complete the entire study you will still be compensated at a pro-rated amount of $5 every hour.

10. Voluntary Participation

Participation in this study is voluntary. You may refuse to participate, refuse to answer any questions or withdraw from the study at any time with no effect on your future care, academic status or employment.

11. Confidentiality

All information about you will be kept strictly confidential. All study data will be securely stored in locked filing cabinets and in password protected computers. All study data will be destroyed after completion of the research project. The results of this study may be published or disclosed to other people in a way that will not allow you to be identified. Any recordings taken during the study will be erased if you so wish.

12. Contacts for Further Information

If you require any further information regarding this research project or your participation in the study you may contact Jessica Grahn by email on [redacted]
If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Research Ethics [redacted] email: [redacted]

13. Publication

If the results of the study are published, your name will not be used. If you would like to receive a copy of any potential study results, please contact Jessica Grahn by email on [redacted]

This letter is yours to keep for future reference.

Consent Statement

Western
The Brain and
Mind Institute

Consent Form

Project Title: Walking at different speeds

Study Investigator's Name: Dr. Jessica Grahn

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Participant's Name (please print): _____

Participant's Signature: _____

Date: _____

Person Obtaining Informed Consent (please print): _____

Signature: _____

Date: _____

Appendix D: Stimuli Database for Study 1.

Song Title	Hypothesized Familiarity Condition	Hypothesized Groove Condition
Call Me Maybe	High	High
Fancy	High	High
Gangham Style	High	High
Moves Like Jagger	High	High
Party Rock Anthem	High	High
The Entertainer	High	High
All of Me	High	Low
Fur Elise	High	Low
Imagine	High	Low
My Heart Will Go On	High	Low
Say Something	High	Low
Scientist	High	Low
Somebody That I Used To Know	High	Low
Someone Like You	High	Low
Stay With Me	High	Low
Bar Music	Low	High
Gayrigg	Low	High
King Charles	Low	High
Muy Tranquilo	Low	High
Notes	Low	High
Ol Country	Low	High
Zumba Latine	Low	Low
A Walk	Low	Low
Cain And Abel	Low	Low
Colorado	Low	Low
Everything You Do Is A Balloon	Low	Low
Lullaby	Low	Low

Appendix E: Original 4-Way ANOVA results for spatial and temporal gait parameters not reported in Study 1 (Chapter 3).

	Step Length (cm)			Stride Width (cm)			Cadence (steps/min)			Stride Velocity (cm/sec)		
	F-Value	*p*-Value	*np2*	*F*-Value	*p* Value	*np2*	*F*-Value	*p* Value	*np2*	*F*-Value	*p* Value	*np2*
Familiarity	1.051	.308	.013	4.811	.031	.055	.710	.402	.009	1.463	.230	.018
Familiarity * Instruction	1.456	.231	.017	1.695	.197	.020	1.321	.254	.016	3.560	.063	.042
Familiarity *BP	.356	.552	.004	.013	.910	.000	.001	.980	.000	.064	.800	.001
Familiarity*Instruction*BP	.656	.420	.008	4.864	.030	.056	.218	.642	.003	.996	.321	.012
Groove	73.557	.000	.473	.735	.394	.009	53.113	.000	.393	91.842	.000	.528
Groove*Instruction	.017	.898	.000	2.594	.111	.031	1.310	.256	.016	.926	.339	.011
Groove*BP	19.616	.000	.193	.392	.533	.005	16.988	.000	.172	26.925	.000	.247
Groove*Instruction*BP	.016	.899	.000	.652	.422	.008	.616	.435	.007	.727	.396	.009
Familiarity*Groove	.001	.980	.000	.003	.960	.000	.219	.641	.003	.273	.603	.003
Familiarity*Groove*Instruction	1.173	.282	.014	.009	.926	.000	1.640	.204	.020	2.519	.116	.030
Familiarity*Groove*BP	.221	.640	.003	.278	.599	.003	.014	.906	.000	.080	.778	.001
Familiarity*Groove*Instruction*BP	.000	.990	.000	.002	.967	.000	.042	.838	.001	.000	.996	.000
BP	1.947	.167	.023	.252	.617	.003	1.003	.320	.012	.436	.511	.005
Instruction	.001	.970	.000	6.055	.016	.069	10.690	.002	.115	2.030	.158	.024
Instruction*BP	.097	.756	.001	.313	.577	.004	.009	.926	.000	.063	.802	.001

Note. Bonferonni alpha adjustments were applied to adjust for multiple comparisons. Thus, the critical alpha values for spatial gait parameters is 0.025 and is 0.017 for all temporal measures. BP = Beat Perception. *Np2* = partial eta squared (effect *size).*

Appendix F: Raw DLST means and standard deviations across all four original factors in Study 1 (Chapter 3).

	Baseline	Low Groove		High Groove		Metronome
		Low Familiarity	High Familiarity	Low Familiarity	High Familiarity	
Free Walking						
Poor Beat Perceivers	12.3 (1.3)	12.7 (1.4)	12.8 (1.6)	12.6 (1.8)	12.4 (1.5)	12.8 (1.6)
Good Beat Perceivers	12.1 (1.4)	12.6 (1.4)	12.5 (1.3)	12.3 (1.3)	12.4 (1.4)	12.4 (1.3)
Total	12.2 (1.3)	12.6 (1.4)	12.6 (1.4)	12.4 (1.5)	12.4 (1.4)	12.6 (1.5)
Synchronized Walking						
Poor Beat Perceivers	12.3 (1.6)	12.9 (1.7)	13 (1.7)	12.3 (1.6)	12.1 (1.5)	12.3 (1.4)
Good Beat Perceivers	12 (1.5)	12.7 (1.3)	12.5 (1.5)	12 (1.4)	12.1 (1.4)	12 (1.5)
Total	12.2 (1.6)	12.8 (1.5)	12.7 (1.6)	12.1 (1.5)	12.1 (1.4)	12.1 (1.5)

Note. Raw means and standard deviations for double-limb support time.

Appendix G: Ethics approval, letter of information, and consent forms for Study 2 (Chapter 4).

Western Research

Research Ethics

Western University Health Science Research Ethics Board
HSREB Annual Continuing Ethics Approval Notice

Date: September 16, 2016
Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,Western University

Review Type: Full Board
HSREB File Number: 103089
Study Title: The effects of beat and non-beat factors on gait and the neural mechanisms of beat perception in patients with Parkinson's disease

HSREB Renewal Due Date & HSREB Expiry Date:
Renewal Due -2017/09/30
Expiry Date -2017/10/09

The Western University Health Science Research Ethics Board (HSREB) has reviewed the Continuing Ethics Review (CER) Form and is re-issuing approval for the above noted study.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice (ICH E6 R1), the Ontario Freedom of Information and Protection of Privacy Act (FIPPA, 1990), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB 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 HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

[redacted]

Ethics Officer: [redacted]

[redacted]

Western
The Brain and
Mind Institute

LETTER OF INFORMATION
Healthy Volunteers

The effects of beat and non-beat factors on gait and the neural mechanisms of beat perception in patients with Parkinson's disease

Principal Investigator:

Jessica A. Grahn, Ph.D.,
[redacted]

Introduction

You are being invited to participate in this research study about the effects of external stimuli such as music on walking ability, and the brain mechanisms involved in hearing a beat in music in individuals with and without Parkinson's disease, because you are a healthy individual without Parkinson's disease, who may serve as a control subject in our study.

The purpose of this letter is to provide you with the information that you require in order to make an informed decision for participation in this research project. The research project is divided into two components: (i) a study of the effects of beat and non-beat factors on gait in patients with Parkinson's disease both on medication and off medication (the "Gait Study"), and (ii) a study, using neuroimaging, of the neural mechanisms of beat perception in Parkinson's disease (the "Neuroimaging Study"). The beat is the steady pulse in a song, for example, what you tap your foot to when you listen to music.

You will first be invited to participate in the first study. A subset of participants who show specific performance characteristics in this first behavioral study might be invited to participate in the neuroimaging study. Participation is entirely voluntary, and participation in any single study does not in any way oblige you to participate in another study.

This research will take place at the Brain and Mind Institute at the University of Western Ontario. It is important for you to understand why the research study is being conducted and what it will involve. Please take the time to read this carefully and feel free to ask questions if anything is unclear or there are words or phrases you do not understand. A healthy control group will also participate to help us determine difference between the musical processing and gait in people with no neurological damage compared to PD patients.

(i)Behavioral study

Aim: The purpose of this study is to determine how beat and non-beat factors in musical rhythm influence the way healthy individuals and Parkinson's disease (PD) patients move. The beat is the steady pulse in a song, for example, what you tap your foot to when you listen to music.

Procedure: If you agree to participate in this study component, you will undergo behavioral tasks where you will listen to stimuli and make judgments about the stimuli (e.g., 'Does it have a beat? Is it the same rhythm as the previous stimulus?).

Once complete you will listen to various auditory stimuli while (1) walking on an electronic sensor walkway or (2) reaching to a target by moving a hand-held recording cursor, depending on study assignment. Both reaching and walking study paradigms will record the timing and distance of your movements.

As you are walking, you will be asked to listen to music at a comfortable volume of their choice. You may choose to take rest breaks at any time during the study. If at any time the task becomes too physically demanding or you become tired, you can end the experiment at any time. Parkinson's disease patients will complete this component while **on** their regular dopaminergic medication prior to the testing session.

If you are interested, you may be invited to participate in an extended version of the study, to act as controls for PD patients who will be tested ON or OFF their usual dopamine medications in two sessions. Like the PD patients, you will complete two sessions. The behavioral task for the two sessions will be similar.

Compensation: You will be compensated $10 per 1.5 hours to cover your time, parking and the inconveniences associated with participating in the research project. If you are a first year psychology student recruited from the SONA participant pool at the University of Western Ontario, you will receive 2 credit points for your participation.

Benefits: While this research project will not result in any direct benefit to you, it may help clinicians understand how the brain responds to rhythmic information and walking patterns and therefore be of some benefit to patients in the future.

Risks: This study will employ standard procedures of experimental psychology and the movement recording equipment. There are no known health risks associated with the movement recording equipment; the equipment does not penetrate or abrade the skin.

Participant exclusion criteria

The most important concern is the safety of the participant.

If you have personal medical history of another neurological illness (e.g., stroke, seizure disorder), severe depression or anxiety, substance abuse (ETOH, prescription medication, illicit drugs), you should not participate in this study.

(ii) Neuroimaging study

Aim: The Neuroimaging Study investigates the regions of the brain that are active when people perceive sequences of events that form a rhythm. The purpose of this component is to map and characterize areas of the human brain that are involved in “feeling the beat”.

Procedure: If you agree to participate in this study, you will undergo functional magnetic resonance imaging (fMRI) at the Robarts Research Institute. Functional MRI is a noninvasive brain imaging technique that uses the same machine that is used in magnetic resonance imaging (MRI) for patients. MRI uses a strong magnet and radio waves to make images of the brain. It does not involve x-rays or radiation. When a specific region of the brain is involved in processing information, there is an associated change in brain metabolism and blood flow to that region. These changes can be detected by the MRI scanner as changes in the image signal intensity. These changes are particularly prominent with stronger magnetic fields, which is why 3 Tesla and 7 Tesla scanners are used rather than a 1.5 Tesla scanner used in a clinical setting.

Eligible participants will also be asked to remove any metallic personal effects (jewelry, watch, hair clips, wallet) to be stored in a safe place while being scanned. At the beginning of the session, you will lie down on a table that slowly slides inside the long hollow tube at the centre of the MRI machine. The space within the large magnet is somewhat confined, although we have taken many steps to reduce any "claustrophobic" feelings. The session will last up to two hours, during which you must keep as still as possible, especially during periods lasting approximately five minutes during which the magnet is beeping continuously. You will be made comfortable with pillows, blankets, and foam to help keep your head still. You will hear a muffled banging and beeping noises throughout the scanner operation, but the hearing protection will reduce the sound level to an acceptable level. You will be in voice contact with the operator while you are in the scanner. Between scans we will remind you of specific instructions of the next task. If you want to alert the operator during a scan (i.e., if you find the sound uncomfortably loud), you can use the squeeze ball to end the scan session. You may ask the operator to end the experiment at any time.

During the functional scans, you will listen to various stimuli. You may be asked to listen to the rhythms passively, and/or to make perceptual judgments about the rhythms.

Compensation: You will be compensated $25/hr to cover your time, parking and the inconveniences associated with participating in the research project.

Benefits

While this research project will not result in any direct benefit to you, it may help clinicians understand how the brain responds to rhythmic information and walking patterns and therefore be of some benefit to patients in the future.

Risks:

The Magnetic Resonance Imaging (MRI) system, a non-invasive, common medical diagnostic tool that uses a strong magnetic field, a low frequency magnetic field, and a radio frequency field.
No X-rays are used. As with any technology there is a risk of injury, and in very rare cases, death. MRI the risk of death is less than 1 in 10 million and the risk of injury is less than 1 in 100,000. These risks do not arise from the MRI process itself, but from a failure to disclose or detect MRI incompatible objects in or around the body of the subject or the scanner room. It is therefore very important that you answer all the questions honestly and fully on the MRI screening questionnaire.

Almost all the deaths and injuries related to MRI scans have occurred because the MRI operator did not know that surgically implanted metal hardware (such as a cardiac pacemaker) was present inside the subject during the MRI scan. Other remote risks involve temporary hearing loss from the loud noise inside the magnet. This can be avoided with ear headphone protection that also allows continuous communication between the subject and staff during the scan.

For comparison, the risk of death in an MRI is similar to travelling 10 miles by car, while the risk of injury during an MRI is much less than the risks associated with normal daily activities for 1 hour.

You may not be allowed to continue in this research study if you are unable to have a MRI scan because, for example, you have some MRI incompatible metal in your body, you may be pregnant or attempting to become pregnant, or you may have a drug patch on your skin that contains a metal foil. Should you require a medically necessary MRI scan in the future, the final decision as to whether you can be scanned will be made by a qualified physician considering all the risks and benefits.

The most important safety concern with MRI is to avoid having any metal in your body that is deemed unsafe in a strong magnetic field. Prior to participating, you will be asked to fill out a screening checklist to evaluate whether you meet the eligibility criteria for participation in the Neuroimaging Study. These include precautions to ensure you have no unsafe metal in your body and, if you are female, that you are not pregnant or at risk of conceiving a child. If you have any history of head or eye injury involving metal fragments, if you have ever worked in a metal shop or been a soldier, if you have some type of implanted electrical device (such as a cardiac pacemaker), if you have severe heart disease (including susceptibility to arrhythmias), you should not have an MRI scan. Some surgical implants (e.g., hip or joint replacements) are made of alloys (e.g., titanium) that are non-magnetic and are therefore safe in the MRI scanner. To certify that your surgical implant is safe for the MRI, we must have documentation from your physician before you will be able to participate in the experiment.

Confidentiality

Any information obtained from this research project will be kept confidential. In the event of publication, any data resulting from your participation will be identified only by case number, without any reference to your name or personal information. The data will be stored on a secure computer in a locked room. Both the computer and the room will be accessible only to the experimenters. After completion of the research project, data will be archived on storage disks and stored in a locked room for five years, after which they will be destroyed. Representatives of the University of Western Ontario Health Sciences Research Ethics Board may require access to your records related to this research project or may follow up with you to monitor the conduct of the research project.

Voluntary Participation

Participation in this research project is voluntary. You may refuse to participate, refuse to answer questions or withdraw from the research project at any time with no effect on your future relationship with Western. You should ask to stop the experiment if you feel uncomfortable, claustrophobic or tired.

Estimate of participant's time and number of participants

Each session of the Gait Study will last approximately 1-2 hours. The Neuroimaging Study will last approximately two hours. The entire research project will involve 800 subjects.

Consent Form

You do not waive any legal rights by signing the consent form. You will be provided with a copy of this letter of information and the consent form.

Contact Information

If you would like to receive a copy of the overall results of the research project or if you have any questions about the research project, please feel free to contact the Principal Investigator at the contact information provided on page 1 of this letter.

If you have any questions about your rights as a research participant or the conduct of the study you may contact:

Dr. David Hill, Scientific Director, Lawson Health Research Institute [redacted]

CONSENT FOR RESEARCH PROJECT

The neural mechanisms of rhythm and beat perception

I have read the letter of information, have had the nature of the research project explained to me and I agree to participate. All questions have been answered to my satisfaction.

Dated in _____, this_____ day of_____,20_____.

_____ _____

Name of Participant (Please print) Name of Principal Investigator:

_____ _____

Signature of Participant: Signature of Principal Investigator:

Name of Person Responsible for Obtaining Consent: _____

(Please print)

Signature of Person Responsible for Obtaining Consent: _____

Dated in _____, this_____ day of_____,20_____

Appendix H: Stimulus Databases for Study 2 (Chapter 4).

Stimulus database for participants 45-69 years.

Song Title	Familiarity	Groove
Chatanooga Choo	High	High
William Tell Overture	High	High
It Had to Be You	High	High
The A Train	High	High
In the Mood	High	High
Sing Sing	High	High
Rock Around the Clock	High	High
Trepak	High	High
Carmen Overture	High	High
Swan Lake	High	Low
Lakme Flower Duet	High	Low
Eine Kleine Nachtmusik	High	Low
The Godfather Theme	High	Low
Some Enchanted Evening	High	Low
Nightingale	High	Low
Scarborough Fair	High	Low
Twangy	Low	High
Surfing	Low	High
Bourree	Low	High
Fetes	Low	High
The Drunk	Low	High
Once More	Low	High
Louisiana	Low	High
Nobles Mystic	Low	High
Candy Rock	Low	High
Our Winte rLove	Low	Low
His Hand	Low	Low
Heather	Low	Low
Butterfly	Low	Low
Music Magic	Low	Low
Danse Lente	Low	Low
Roses in December	Low	Low
Albatross	Low	Low

Stimulus database for participants 70+ years.

Song Title	Familiarity	Groove
In The Mood	High	High
Rock Around the Clock	High	High
Twist and Shout	High	High
William Tell Overtire	High	High
Copacabana	High	High
Sing Sing	High	High
Trepak	High	High
I'm a Believe	High	High
Carmen Overture	High	High
Green Onions	High	High
Lakme Flower Duet	High	Low
Something	High	Low
Tome to Say Goodbye	High	Low
Greensleeves	High	Low
Nadia's Theme	High	Low
Exodus	High	Low
Imagine	High	Low
Scarborough Fair	High	Low
Cripple Creek	Low	High
Zone	Low	High
Bourree	Low	High
Louisiana	Low	High
Flip Flip	Low	High
Once More	Low	High
Peach Fuzz	Low	High
Nobles Mystic	Low	High
Fetes	Low	High
Butterfly	Low	Low
Heather	Low	Low
White Keys	Low	Low
His Hand	Low	Low
Danse Lente	Low	Low
Roses in December	Low	Low
To Audrey	Low	Low
Albatross	Low	Low

Appendix I: Follow-up questions regarding perceived synchronization accuracy provided to participants in studies 2 and 3 (Chapter 4 and 5, respectively). Data are not included in this thesis.

Q30

The next set of questions are about your performance during the experiment today.

Q31 Did you try to match your steps (synchronize) with the music while you walked today?

- ○ Yes (1)
- ○ No (2)

Display This Question:

If Did you try to match your steps (synchronize) with the music while you walked today? = Yes

Q32 Did it feel challenging for you to synchronize your steps with the music?

- ○ Yes (1)
- ○ Somewhat (2)
- ○ No (3)

Display This Question:

If Did it feel challenging for you to synchronize your steps with the music? != No

Q37 You indicated that synchronizing with the music felt challenging, or somewhat challenging. Please elaborate on why it felt challenging for you:

_____

_____

Display This Question:

If Did you try to match your steps (synchronize) with the music while you walked today? = Yes

Q34 If you used any strategies to help you synchronize with the beat, please explain below.

_____

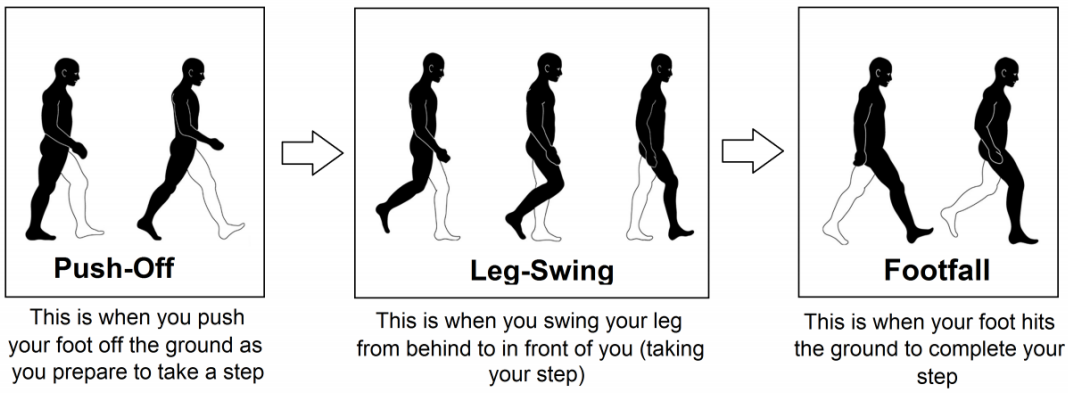
Display This Question:

If Did you try to match your steps (synchronize) with the music while you walked today? = Yes

Q1

These images below represent leg movement during the walking cycle.

The titles correspond to the leg that is coloured in **black**.



Display This Question:

If Did you try to match your steps (synchronize) with the music while you walked today? = Yes

Q33 Please select the image that best represents the movement that you tried to synchronize with the beat of the music by clicking on the appropriate image below:

- ○ Image:PushOff.png (1)
- ○ Image:LegSwing.png (3)
- ○ Image:Heelsrike (4)

End of Block: Default Question Block

Appendix J: Original 4-Way ANOVA results for temporal gait parameters not reported in Chapter 4.

Results from original 2x2x2x2 ANOVAs with Familiarity (high, low); Groove (high, low), Beat perception ability (good, poor), and instructions (free walking, synchronized walking).

	Cadence (steps/min)			Stride Velocity (cm/sec)			DLST (sec)		
	F-Value	*p* Value	*np2*	*F*-Value	*p* Value	*np2*	*F*-Value	*p* Value	*np2*
Familiarity	.696	.409	.017	2.781	.103	.064	.447	.508	.011
Familiarity * Instruction	.021	.886	.001	.000	.987	.000	.108	.744	.003
Familiarity *BP	5.494	.024	.118	1.177	.284	.028	2.272	.139	.053
Familiarity*Instruction*BP	.306	.583	.007	.042	.838	.001	.583	.450	.014
Groove	16.929	.000	.292	22.922	.000	.359	9.235	.004	.184
Groove*Instruction	.314	.578	.008	.594	.445	.014	.204	.654	.005
Groove*BP	.725	.400	.017	.523	.474	.013	.801	.376	.019
Groove*Instruction*BP	3.838	.057	.086	3.397	.073	.077	2.307	.137	.053
Familiarity*Groove	2.499	.122	.057	1.781	.189	.042	.608	.440	.015
Familiarity*Groove*Instruction	.152	.699	.004	.186	.669	.005	1.035	.315	.025
Familiarity*Groove*BP	.252	.619	.006	.166	.686	.004	.248	.621	.006
Familiarity*Groove*Instruction*BP	1.379	.247	.033	.817	.371	.020	.147	.703	.004
Instruction	6.348	.016	.134	3.660	.063	.082	1.931	.172	.045
BP	.947	.336	.023	.298	.588	.007	.650	.425	.016
Instruction*BP	.766	.387	.018	1.163	.287	.028	.881	.353	.021

Note. Bonferonni alpha adjustments were applied to adjust for multiple comparisons. Thus, the critical alpha value is .017 for all temporal measures. BP = Beat Perception. *np2* = partial eta squared (effect *size).*DLST = double limb support time.

	Step Length Variability (CV)			Step Time Variability (CV)			Stride Velocity Variability (CV)		
	F-Value	*p*-Value	*np2*	*F*-Value	*p* Value	*np2*	*F*-Value	*p* Value	*np2*
Familiarity	3.010	.090	.068	2.910	.096	.066	1.830	.184	.043
Familiarity * Instruction	.287	.595	.007	.004	.951	.000	.563	.457	.014
Familiarity *BP	3.270	.078	.074	1.503	.227	.035	.002	.966	.000
Familiarity*Instruction*BP	3.224	.080	.073	5.667	.022	.121	1.991	.166	.046
Groove	2.978	.092	.068	.384	.539	.009	3.183	.082	.072
Groove*Instruction	.010	.922	.000	.415	.523	.010	.491	.488	.012
Groove*BP	.002	.964	.000	.966	.331	.023	.231	.633	.006
Groove*Instruction*BP	.337	.564	.008	.227	.636	.006	.518	.476	.012
Familiarity*Groove	.009	.923	.000	.891	.351	.021	.372	.545	.009
Familiarity*Groove*Instruction	5.405	.025	.116	.062	.804	.002	.142	.708	.003
Familiarity*Groove*BP	.022	.884	.001	.191	.665	.005	1.130	.294	.027
Familiarity*Groove*Instruction*BP	2.996	.091	.068	1.479	.231	.035	.820	.370	.020
BP	.705	.406	.017	1.335	.255	.032	.540	.467	.013
Instruction	1.781	.189	.042	.019	.890	.000	.564	.457	.014
Instruction*BP	.450	.506	.011	3.236	.079	.073	3.282	.077	.074

Note. Bonferonni alpha adjustments were applied to adjust for multiple comparisons. Thus, the critical alpha for variability measures is .017. BP = Beat Perception. np2 = partial eta squared (effect size).

Appendix K: Ethics approvals, letter of information, and consent forms for study 3 (Chapter 5).

Western Research

Research Ethics

Western University Health Science Research Ethics Board
HSREB Annual Continuing Ethics Approval Notice

Date: September 18, 2017
Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology,

Review Type: Full Board
HSREB File Number: 103089
Study Title: The effects of beat and non-beat factors on gait and the neural mechanisms of beat perception in patients with Parkinson's disease

HSREB Renewal Due Date & HSREB Expiry Date:
Renewal Due -2018/09/30
Expiry Date -2018/10/09

The Western University Health Science Research Ethics Board (HSREB) has reviewed the Continuing Ethics Review (CER) Form and is re-issuing approval for the above noted study.

The Western University HSREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the International Conference on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use Guideline for Good Clinical Practice (ICH E6 R1), the Ontario Freedom of Information and Protection of Privacy Act (FIPPA, 1990), the Ontario Personal Health Information Protection Act (PHIPA, 2004), Part 4 of the Natural Health Product Regulations, Health Canada Medical Device Regulations and Part C, Division 5, of the Food and Drug Regulations of Health Canada.

Members of the HSREB 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 HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

[redacted]

EO: [redacted]

Western Research

Date: 25 September 2018

To: Jessica Grahn

Project ID: 103089

Study Title: The effects of beat and non-beat factors on gait and the neural mechanisms of beat perception in patients with Parkinson's disease

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

REB Meeting Date: 16/Oct/2018

Date Approval Issued: 25/Sep/2018

REB Approval Expiry Date: 09/Oct/2019

Dear Jessica Grahn,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

Western University REB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The REB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

[redacted]

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Western
The Brain and
Mind Institute

LETTER OF INFORMATION
Patient Volunteers

The effects of beat and non-beat factors on gait and the neural mechanisms of beat perception in patients with Parkinson's disease

Principal Investigator:

Jessica A. Grahn, Ph.D.,
[redacted]

Introduction

You are being invited to participate in this research study about the effects of external stimuli such as music on walking ability, and the brain mechanisms involved in hearing a beat in music in individuals with and without Parkinson's disease, because you are an individual with Parkinson's disease, which is our participant group of interest.

The purpose of this letter is to provide you with the information that you require in order to make an informed decision for participation in this research project. The research project is divided into two studies: (i) a behavioral study of the effects of beat and non-beat factors on gait in patients with Parkinson's disease (the "Gait Study"), and and (ii) a study using neuroimaging to evaluate the neural mechanisms of beat perception in Parkinson's disease (the "Neuroimaging Study"). The beat is the steady pulse in a song, for example, what you tap your foot to when you listen to music.

You will first be invited to participate in the first behavioral study. A subset of participants who show specific performance characteristics in this first behavioral study might be invited to participate in the neuroimaging study. Participation is entirely voluntary, and participation in any single study does not in any way oblige you to participate in another study.

This research will take place at the Brain and Mind Institute at the University of Western Ontario. It is important for you to understand why the research study is being conducted and what it will involve. Please take the time to read this carefully and feel free to ask questions if anything is unclear or there are words or phrases you do not understand. A healthy control group will also participate to help us determine difference between the musical processing and gait in people with no neurological damage compared to PD patients.

(i)Behavioral study

Aim: The purpose of this study is to determine how beat and non-beat factors in musical rhythm influence the way healthy individuals and Parkinson's disease (PD) patients move. The beat is the steady pulse in a song, for example, what you tap your foot to when you listen to music.

Procedure: If you agree to participate in this study component, you will undergo behavioral tasks where you will listen to stimuli and make judgments about the stimuli (e.g., 'Does it have a beat? Is it the same rhythm as the previous stimulus?).

Once complete you will listen to various auditory stimuli while (1) walking on an electronic sensor walkway or (2) reaching to a target by moving a hand-held cursor, depending on study assignment. Both reaching and walking study paradigms will record the timing and distance of your movements.

As you are moving, you will be asked to listen to music at a comfortable volume of their choice. You may choose to take rest breaks at any time during the study. If at any time the task becomes too physically demanding or you become tired, you can end the experiment at any time. Parkinson's disease patients will complete this component while **on** their regular dopaminergic medication prior to the testing session.

If you are interested, you may be invited to participate in an extended version of the study where you will be tested either ON or OFF your usual dopamine medications. In the ON condition, you will take your dopamine medication as usual. In the OFF condition, you will abstain from the regular dopaminergic medications for approximately 12 hours prior to half of the testing sessions.

Compensation

You will be compensated $10 per 1.5 hours to cover your time, parking and the inconveniences associated with participating in the research project.

Risks

This study will employ standard procedures of experimental psychology and the sensor walkway. There are no known health risks associated with themovement recording equipment; the equipment does not penetrate or abrade the skin.

If you participate in the extended version of the study where you are tested ON or OFF your medication regime, , you may experience an increase in your PD symptoms when OFF-medication, which could be unpleasant. Theoretically, there is a risk of developing hyperpyrexia-rigidity syndrome. The symptoms of this syndrome simulate those of neuroleptic-malignant syndrome, including fever, rigidity, and autonomic instability. However this syndrome is typically developed when a patient has been without medication for 72-96 hours.

Participant exclusion criteria

The most important concern is the safety of the participant.

For patients interested in being tested on and off treatment; we ask that participants who have a history or are currently being treated with deep brain stimulation or other

neurosurgical procedures to refrain from participating to ensure participant safety. PD patients who are in immediate need for surgery or any other clinical procedure should refrain from participating in this study component to ensure participant safety. If you are being treated with Donepezil, Rivastigmine, Galantamine, or Memantine, have personal medical history of another neurological illness (e.g., stroke, seizure disorder), severe depression or anxiety, substance abuse (ETOH, prescription medication, illicit drugs), you should not participate in this study.

(ii) Neuroimaging study

Aim: The Neuroimaging Study investigates the regions of the brain that are active when people perceive sequences of events that form a rhythm. The purpose of this component is to map and characterize areas of the human brain that are involved in "feeling the beat".

If you agree to participate in this study, you will undergo functional magnetic resonance imaging (fMRI) at the Robarts Research Institute. Functional MRI is a noninvasive brain imaging technique that uses the same machine that is used in magnetic resonance imaging (MRI) for patients. MRI uses a strong magnet and radio waves to make images of the brain. It does not involve x-rays or radiation. When a specific region of the brain is involved in processing information, there is an associated change in brain metabolism and blood flow to that region. These changes can be detected by the MRI scanner as changes in the image signal intensity. These changes are particularly prominent with stronger magnetic fields, which is why 3 Tesla and 7 Tesla scanners are used rather than a 1.5 Tesla scanner used in a clinical setting.

Eligible participants will also be asked to remove any metallic personal effects (jewelry, watch, hair clips, wallet) to be stored in a safe place while being scanned. At the beginning of the session, you will lie down on a table that slowly slides inside the long hollow tube at the centre of the MRI machine. The space within the large magnet is somewhat confined, although we have taken many steps to reduce any "claustrophobic" feelings. The session will last up to two hours, during which you must keep as still as possible, especially during periods lasting approximately five minutes during which the magnet is beeping continuously. You will be made comfortable with pillows, blankets, and foam to help keep your head still. You will hear a muffled banging and beeping noises throughout the scanner operation, but the hearing protection will reduce the sound level to an acceptable level. You will be in voice contact with the operator while you are in the scanner. Between scans we will remind you of specific instructions of the next task. If you want to alert the operator during a scan (i.e., if you find the sound uncomfortably loud), you can use the squeeze ball to end the scan session. You may ask the operator to end the experiment at any time.

During the functional scans, you will listen to various stimuli. You may be asked to listen to the rhythms passively, and/or to make perceptual judgments about the rhythms.

Compensation

You will be compensated $25/hr to cover your time, parking and the inconveniences associated with participating in the research project.

Benefits

While this research project will not result in any direct benefit to you, it may help clinicians understand how the brain responds to rhythmic information and walking patterns and therefore be of some benefit to patients in the future.

Risks

The Magnetic Resonance Imaging (MRI) system, a non-invasive, common medical diagnostic tool that uses a strong magnetic field, a low frequency magnetic field, and a radio frequency field.No X-rays are used. As with any technology there is a risk of injury, and in very rare cases, death. MRI the risk of death is less than 1 in 10 million and the risk of injury is less than 1 in 100,000. These risks do not arise from the MRI process itself, but from a failure to disclose or detect MRI incompatible objects in or around the body of the subject or the scanner room. It is therefore very important that you answer all the questions honestly and fully on the MRI screening questionnaire.

Almost all the deaths and injuries related to MRI scans have occurred because the MRI operator did not know that surgically implanted metal hardware (such as a cardiac pacemaker) was present inside the subject during the MRI scan. Other remote risks involve temporary hearing loss from the loud noise inside the magnet. This can be avoided with ear headphone protection that also allows continuous communication between the subject and staff during the scan.

For comparison, the risk of death in an MRI is similar to travelling 10 miles by car, while the risk of injury during an MRI is much less than the risks associated with normal daily activities for 1 hour.

You may not be allowed to continue in this research study if you are unable to have a MRI scan because, for example, you have some MRI incompatible metal in your body, you may be pregnant or attempting to become pregnant, or you may have a drug patch on your skin that contains a metal foil. Should you require a medically necessary MRI scan in the future, the final decision as to whether you can be scanned will be made by a qualified physician considering all the risks and benefits.

The most important safety concern with MRI is to avoid having any metal in your body that is deemed unsafe in a strong magnetic field. Prior to participating, you will be asked to fill out a screening checklist to evaluate whether you meet the eligibility criteria for participation in the Neuroimaging Study. These include precautions to ensure you have no unsafe metal in your body and, if you are female, that you are not pregnant or at risk of conceiving a child. If you have any history of head or eye injury involving metal fragments, if you have ever worked in a metal shop or been a soldier, if you have some type of implanted electrical device (such as a cardiac pacemaker), if you have severe heart disease (including susceptibility to arrhythmias), you should not have an MRI scan. Some surgical implants (e.g., hip or joint replacements) are made of alloys (e.g., titanium) that are non-magnetic and are therefore safe in the MRI scanner. To certify that your surgical implant is safe for the MRI, we must have documentation from your physician before you will be able to participate in the experiment.

Confidentiality

Any information obtained from this research project will be kept confidential. In the event of publication, any data resulting from your participation will be identified only by case number, without any reference to your name or personal information. The data will be stored on a secure computer in a locked room. Both the computer and the room will be accessible only to the experimenters. After completion of the research project, data will be archived on storage disks and stored in a locked room for five years, after which they will be destroyed. Representatives of the University of Western Ontario Health Sciences Research Ethics Board may require access to your records related to this research project or may follow up with you to monitor the conduct of the research project.

Voluntary Participation

Participation in this research project is voluntary. You may refuse to participate, refuse to answer questions or withdraw from the research project at any time with no effect on your future care. You should ask to stop the experiment if you feel uncomfortable, claustrophobic or tired.

Estimate of participant's time and number of participants

Each session of the Gait Study will last approximately one hour. The Neuroimaging Study will last approximately two hours. The entire research project will involve 800 subjects.

Consent Form

You do not waive any legal rights by signing the consent form. You will be provided with a copy of this letter of information and the consent form.

Contact Information

If you would like to receive a copy of the overall results of the research project or if you have any questions about the research project, please feel free to contact the Principal Investigator at the contact information provided on page 1 of this letter.

If you have any questions about your rights as a research participant or the conduct of the study you may contact:

[redacted]

CONSENT FOR RESEARCH PROJECT

The neural mechanisms of rhythm and beat perception

I have read the letter of information, have had the nature of the research project explained to me and I agree to participate. All questions have been answered to my satisfaction.

Dated in _____, this_____ day of_____,20_____.

_____	_____
Name of Participant (Please print)	Name of Principal Investigator:
_____	_____
Signature of Participant:	Signature of Principal Investigator:

Name of Person Responsible for Obtaining Consent: _____

(Please print)

Signature of Person Responsible for Obtaining Consent: _____

Dated in _____, this_____ day of_____,20_____

Appendix L: Stimulus database for PD participants in study 3 (Chapter 5).

Song Title	Familiarity	Groove
Copacabana	High	High
In the Mood	High	High
Green Onions	High	High
Twist and Shout	High	High
William Tell Overture	High	High
Something	High	Low
Nadia Theme	High	Low
Imagine	High	Low
Scarborough Fair	High	Low
Exodus	High	Low
Candy Rock	Low	High
Flip Flop	Low	High
Peach Fuzz	Low	High
Once More	Low	High
Cripple Creek	Low	High
Roses in December	Low	Low
White Keys	Low	Low
Albatross	Low	Low
To Audrey	Low	Low
Lullaby	Low	Low

Appendix M: Goldsmith Musical Sophistication Index musical training subscale used in Study 3 (Chapter 5).

Please circle the most appropriate category:

Please circle the most appropriate category:	1 Completely Disagree	2 Strongly Disagree	3 Disagree	4 Neither Agree nor Disagree	5 Agree	6 Strongly Agree	7 Completely Agree
1. I have never been complimented for my talents as a musical performer.	1	2	3	4	5	6	7
2. I would not consider myself a musician.	1	2	3	4	5	6	7

3. I engaged in regular, daily practice of a musical instrument (including voice) for 0 / 1 / 2 / 3 / 4-5 / 6-9 / 10 or more years.

4. At the peak of my interest, I practiced 0 / 0.5 / 1 / 1.5 / 2 / 3-4 / 5 or more hours per day on my primary instrument.

5. I have had formal training in music theory for 0 / 0.5 / 1 / 2 / 3 / 4-6 / 7 or more years.

6. I have had 0 / 0.5 / 1 / 2 / 3-5 / 6-9 / 10 or more years of formal training on a musical instrument (including voice) during my lifetime.

7. I can play 0 / 1 / 2 / 3 / 4 / 5 / 6 or more musical instruments.

Appendix N: Original 4-Way ANOVA results from study 3 (Chapter 5).

Results from original 2x2x2x2 ANOVAs with Familiarity (high, low); Groove (high, low), Beat perception ability (good, poor), and instructions (free walking, synchronized walking).

	Step Length (cm)			Stride Width (cm)			Cadence (steps/min)			Stride Velocity (cm/sec)			DLST (sec)		
	F	*p*	*np2*	*F*	*p*	*np2*	*F*	*p*	*np2*	*F*	*p*	*np2*	*F*	*p*	*np2*
Familiarity	0.17	0.69	0.01	2.31	0.15	0.12	0.11	0.75	0.01	0.06	0.81	0.00	0.56	0.47	0.03
Familiarity * Instruction	0.24	0.63	0.01	1.55	0.23	0.08	0.19	0.67	0.01	0.18	0.67	0.01	0.47	0.50	0.03
Familiarity *BP	1.51	0.24	0.08	2.86	0.11	0.14	1.81	0.20	0.10	2.16	0.16	0.11	1.18	0.29	0.06
Familiarity*Instruction*BP	0.99	0.33	0.05	1.12	0.31	0.06	1.34	0.26	0.07	1.68	0.21	0.09	0.88	0.36	0.05
Groove	11.90	0.00	0.41	0.61	0.45	0.03	21.96	0.00	0.56	24.07	0.00	0.59	24.20	0.00	0.59
Groove*Instruction	1.51	0.24	0.08	0.08	0.78	0.00	1.83	0.19	0.10	2.17	0.16	0.11	2.02	0.17	0.11
Groove*BP	1.12	0.31	0.06	0.13	0.72	0.01	0.05	0.83	0.00	0.50	0.49	0.03	0.59	0.45	0.03
Groove*Instruction*BP	2.64	0.12	0.13	0.04	0.85	0.00	0.03	0.87	0.00	0.62	0.44	0.04	1.29	0.27	0.07
Familiarity*Groove	0.68	0.42	0.04	1.82	0.20	0.10	0.57	0.46	0.03	1.05	0.32	0.06	0.00	0.95	0.00
Familiarity*Groove*Instruction	1.58	0.23	0.09	0.07	0.80	0.00	0.05	0.83	0.00	0.51	0.49	0.03	3.10	0.10	0.15
Familiarity*Groove*BP	0.04	0.85	0.00	0.63	0.44	0.04	6.33	0.02	0.27	2.06	0.17	0.11	0.25	0.62	0.01
Familiarity*Groove*Instruction*BP	0.35	0.56	0.02	0.43	0.52	0.02	2.06	0.17	0.11	0.36	0.56	0.02	0.00	0.98	0.00
Instruction	1.26	0.28	0.07	2.31	0.15	0.12	2.73	0.12	0.14	3.10	0.10	0.15	1.36	0.26	0.07
BP	0.56	0.47	0.03	0.03	0.88	0.00	0.18	0.68	0.01	0.10	0.75	0.01	0.00	1.00	0.00
Instruction*BP	0.63	0.44	0.04	0.23	0.64	0.01	0.29	0.60	0.02	0.41	0.53	0.02	0.68	0.42	0.04

Note. Bonferonni alpha adjustments were applied to adjust for multiple comparisons. Thus, the critical alpha value is 0.025 for spatial measures (step length and width) and is .017 for all temporal measures (cadence, velocity, DLST). BP = Beat Perception. *np2* = partial eta squared (effect *size).*DLST = double limb support time.

Results from original 2x2x2x2 ANOVAs with Familiarity (high, low); Groove (high, low), Beat perception ability (good, poor), and instructions (free walking, synchronized walking).

	Step Length Variability (CV)			Step Time Variability (CV)			Stride Velocity Variability (CV)		
	F	*p*	*np2*	*F*	*p*	*np2*	*F*	*p*	*np2*
Familiarity	5.02	0.04	0.23	0.51	0.49	0.03	1.22	0.28	0.07
Familiarity * Instruction	0.00	0.98	0.00	0.06	0.81	0.00	0.36	0.56	0.02
Familiarity *BP	0.82	0.38	0.05	0.64	0.44	0.04	0.09	0.77	0.01
Familiarity*Instruction*BP	4.65	0.05	0.21	1.12	0.31	0.06	3.11	0.10	0.15
Groove	0.09	0.77	0.01	1.26	0.28	0.07	3.13	0.09	0.16
Groove*Instruction	0.40	0.53	0.02	2.21	0.16	0.12	0.70	0.41	0.04
Groove*BP	0.00	0.96	0.00	0.04	0.85	0.00	0.33	0.57	0.02
Groove*Instruction*BP	0.00	0.99	0.00	1.65	0.22	0.09	0.00	0.99	0.00
Familiarity*Groove	2.03	0.17	0.11	0.95	0.34	0.05	0.05	0.82	0.00
Familiarity*Groove*Instruction	0.65	0.43	0.04	0.00	0.98	0.00	0.12	0.74	0.01
Familiarity*Groove*BP	0.29	0.60	0.02	0.67	0.43	0.04	0.00	0.95	0.00
Familiarity*Groove*Instruction*BP	4.47	0.05	0.21	0.79	0.39	0.04	0.48	0.50	0.03
Instruction	0.42	0.53	0.02	0.01	0.91	0.00	0.00	0.95	0.00
BP	0.09	0.77	0.01	0.00	1.00	0.00	0.69	0.42	0.04
Instruction*BP	0.04	0.84	0.00	0.15	0.71	0.01	0.25	0.62	0.01

Note. Bonferonni alpha adjustments were applied to adjust for multiple comparisons. Thus, the critical alpha for variability measures is .017. BP = Beat Perception. np2 = partial eta squared (effect size).

Curriculum Vitae

Education

Combined MScOT (2017)/PhD in Health & Rehabilitation Sciences 2013-Present

Western University, London ON Canada

Thesis: Individualization of rhythmic auditory cues to manage gait impairments in Parkinson's disease.
Supervisors: Dr. Jessica A. Grahn & Dr. Jeffrey D. Holmes

BA Honours Psychology (minors in Criminology and French) 2009-2013

St. Thomas University, Fredericton NB Canada

Thesis: Canadian defense lawyers' knowledge of factors influencing eyewitness fallibility.
Supervisor: Dr. Ian Fraser

Peer-Reviewed Publications

2019 **Ready, E. A.,** McGarry, L. M., Rinchon, C., Holmes, J. D., & Grahn, J. A. Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues. *Gait & Posture, 68. 555-561*.

2018 Kirkpatrick, L., Brown, H., Searle, M., Smythe, R., **Ready, E.**, & Kennedy, K. The impact of a one-to-one iPad initiative on Grade 7 students' achievement in Language Arts, Mathematics, and Learning Skills. *Computers in the Schools.*

2016 Lutz, S., Holmes, J., **Ready, E**., Jenkins, M., & Johnson, A. Clinical presentation of anxiety in Parkinson's disease: A scoping review. *Occupational Therapy Journal of Research: Occupation, Participation, and Health*.

2016 Kogutek, D., Holmes, J., Grahn, J., Lutz, S., & **Ready, E. A.** Active Music Therapy and physical improvements from rehabilitation for neurological conditions. *Advances in Mind-Body Medicine, 30*(4).

2016 **Ready, E. A***, Lee, J.*****, Davis, E*., & Doyle, P. C. Purposefulness as a critical factor in functioning, disability and health. *Clinical Rehabilitation.* **** = equal first authorship***

2016 Fraser, I., Bond-Fraser, L., Morrison, B., & **Ready, E. A**. Canadian prosecutors' knowledge and beliefs concerning the science behind the fallibility of eyewitness testimony. *Criminal Law Quarterly, 62.*

2015 Holmes, J. D., Brigham, K. L., Jenkins, M. E., **Ready, E. A.,** Lutz, S. G., Johnson, A. M., & Grahn, J. A. The effects of manipulating spatial location of visual cue placement on gait among individuals with Parkinson's Disease: A pilot study. *Physical and Occupational Therapy in Geriatrics, 33*(3)*.*

2015 Fraser, I., Bond-Fraser, L., Waite, K., **Ready, E**., & Morrison, B. The science behind the fallibility of memory: Is it common knowledge? *Journal of Behavioral and Social Sciences.1*(1).

2014 Fraser, I., **Ready, E. A**., & Bond-Fraser, L. Canadian trial lawyers' understanding of scientific evidence concerning the fallibility of eyewitness testimony. *Criminal Law Quarterly*, *61.*

2012 Bond-Fraser, L., Fraser, I. & **Ready, E. A.** To legislate or not to legislate: Encouraging the law to recognize advances in the science of eyewitness testimony. *Perspectives, 15.*

2012 Fraser, I., Bond-Fraser, L., **Ready, E. A.** & Houlihan, M. Research into eyewitness accuracy: Is it being taught to law students? *Alberta Law Review Supplement.*

Other Scholarly Publications

2014 Bartlett D, Skarakis-Doyle E and members of the Rehabilitation Sciences Journal Club, Health and Rehabilitation Sciences Program at Western (Cox S., Davis E., Gregory M., Hope A., Izaryk K., Jeevanantham D., Kogutek D., Lee J., Lutz S., **Ready E.A.**, and Doyle P.). Response to the World Health Organization's request for comments on the document: How to Use the ICF: A Practical Manual for using the International Classification of Functioning, Disability and Health, October 2013.

2014 Fraser, I., Bond-Fraser, L., Morrison, B., & **Ready, E. A.** The general knowledge of criminal and civil litigation lawyers concerning the science of eyewitness fallibility. *Solicitor's Journal*.

Conference Presentations (Oral)

2017 **Ready, E. A.,** Holmes, J. D., & Grahn, J. A. Gait changes in response to music-based rhythmic auditory stimulation in healthy older adults: strategies for individualization. Individualization of music-based auditory cueing. *Health and Rehabilitation Sciences Graduate Research Conference*, London ON, February**. (Best Oral Presentation Award received).**

2017 Kirkpatrick, L.C., Searle, M., Brown, H.M., Sauder, A., Smyth, R., & **Ready, E.** The impact of a 1:1 iPad initiative on intermediate students' language, mathematics, and learning skills achievement. *Annual Conference of the Canadian Society for Studies in Education*, Toronto, Ontario. May.

2016 Fraser, I., Bond-Fraser, L., **Ready, E. A**., & Morrison, B. Canadian prosecutors' knowledge and beliefs concerning the science behind the fallibility of memory. *American Association for the Behavioral and Social Sciences*. Las Vegas, NV, February.

2016 Kogutek, D., Holmes, J., Grahn, J., Lutz, S., & **Ready, E. A.** Active Music Therapy and physical improvements in rehabilitation. *Online Conference for Music Therapy.* February.

2015 **Ready, E. A**., McGarry, L. M. J., Rinchon, C., Holmes, J. D., & Grahn, J. A. Asynchronized Rhythmic Auditory Stimulation: The influence of manipulating familiarity and groove on non-impaired gait. *Health and Rehabilitation Sciences Graduate Research Conference*, London ON, February**. (Best Oral Presentation Award received).**

2014 Fraser, I. **Ready, E.,** Bond-Fraser, L., & Morrison, B. Is the science concerning the fallibility of memory common knowledge? *Annual Conference of the American Association for the Behavioral and Social Science*s. Las Vegas, NV, February.

2013 **Ready, E. A.** Lawyers' belief and accuracy of knowledge pertaining to eyewitness research. *Science Atlantic Psychology Conference.* Halifax, NS, May. **(Science Communication Award received).**

2012 Bond-Fraser, L., Fraser, I. & **Ready, E. A.** To legislate or not to legislate: Encouraging the law to recognize advances in the science of eyewitness testimony. *Annual Conference of the American Association for the Behavioral and Social Sciences.* Las Vegas, NV. February.

Conference Presentations (Poster)

2018 **Ready, E. A**., Holmes, J. D., & Grahn, J. A. Beat Perception Ability and Familiarity with Music alter Gait in Older Adults during Auditory Cueing. *Society for Neuroscience Annual Meeting*. San Diego, CA. November.

2017 **Ready, E. A.**, Mcgarry, L. M., Holmes, J. D., & Grahn, J. A. In sync with the groove: How is synchronization accuracy altered by cue pace and perceived groove during rhythmic auditory stimulation? *International Society for Posture and Gait Research World Congress*. Fort Lauderdale, FL.

2016 **Ready, E. A.**, Mcgarry, L. M., Holmes, J. D., & Grahn, J. A. Higher levels of perceived groove improve spatiotemporal parameters of gait in accelerated rhythmic auditory stimulation. *Society for Neuroscience Annual Meeting.* San Diego, CA. November.

2016 McGarry, L.M, **Ready, E.A**, Rinchon, C., Holmes, J.D., and Grahn, J.A. Walking to music: How instructions to synchronize alter gait in good and poor beat perceivers. *International Conference for Music Perception and Cognition*, San Francisco, CA. July.

2015 Rinchon, C., McGarry, L. M. J., **Ready, E. A.**, & Grahn, J. A. Familiarity with music increases stride length in rhythmic auditory cueing. *Brain and Mind Institute Symposium.* London, ON, September.

2015 McGarry, L. M. J., Rinchon, C., **Ready, E. A.**, Holmes, J. D., & Grahn, J. A. Investigating music-based rhythmic auditory stimulation for gait rehabilitation: Weak beat perceivers perform better without instructions to synchronize. *Brain and Mind Institute Symposium.* London, ON, September.

2015 **Ready, E. A.,** McGarry, L. M. J., Rinchon, C. Holmes, J. D., & Grahn, J. A. Free-walking and synchronized rhythmic auditory stimulation: Effects of individual differences in beat perception, dance and music training on gait. *International Society for the Study of Individual Differences Conference*. London, ON, July.

2015 **Ready, E. A**., McGarry, L. M. J., Rinchon, C., Holmes, J. D., & Grahn, J. A. Free-walking rhythmic auditory stimulation: Effects of familiarity and groove on gait. *Canadian Society for Brain, Behaviour and Cognitive Science Annual Conference*. Ottawa, ON, June.

2014 **Ready, E. A**., Lutz, S., Brigham, K., Jenkins, M., & Holmes, J. Management of freezing of gait: Longitudinal efficacy of auditory cueing. *Canadian Association of Occupational Therapists National Conference*. Fredericton, NB, May.

Invited Talks

2019	Music, Movement, & the Brain – Music and the Brain Workshop, Carnegie Mellon University Dalcroze Training Centre
2018	Music & Parkinson's disease – Parkinson Society of Southwestern Ontario Webinar Series
2013	Eyewitness Fallibility – Psych. & the Law 2233, St. Thomas University
2013	Eyewitness Evidence – Wrongful Convictions 3503 St. Thomas University
2012	Eyewitness Education in Law Schools – Psych. & the Law 2233, St. Thomas University

Awards and External Funding

2017	Ontario Society of Occupational Therapists Student Award
2017	Future Scholar Award (Canadian Occupational Therapy Foundation, $100)
2017-2018	Ontario Graduate Scholarship (Western University, $15, 000)
2016-2017	Ontario Graduate Scholarship (Western University, $15, 000)
2014-2015	Ontario Graduate Scholarship (Western University, $15, 000)
2013	Certificate of Excellence for Honours in Psychology (Canadian Psychological Association)
2013	Science Communication Award (Science Atlantic Psychology Conference, $200)
2009-2013	Dean's List (St. Thomas University)
2011	Rev. A. L. McFadden Scholarship, (St. Thomas University, $2, 000)
2010	Outstanding Scholar Award (St. Thomas University, $1,000)

Student Research Supervision (with Dr. Jessica Grahn)

2019	Shaily Brahmbhatt (2018-), Renee Ruguett (2018-)
2018	Megan Fung (2017-), Sangmin Lee, Suzanna Geng (2017-)
2017	Sulman Zahid, Anne-Maude Patouillard
2016	Alexis Harrington (2014-), David Prete, Anjali Kumar, Annie Wu, Daphne Hui
2015	Lauren Edwards, Albert Kim

Public Engagement

2018	Parkinson Society Southwestern Ontario Living Well Conferences
2018	Parkinson Society Southwestern Ontario Support Groups
2018	Shadow a Researcher Day (research demonstrations)
2017	Parkinson Society Southwestern Ontario Walk-it
2017	Brain Health Network Brain Fair (research demonstrations)
2016-2017	Occupational Therapy (UWO) Grassroots Co-Chair
2016	Movement Neuroscience KIN3480 (research demonstrations)
2016	Banting Secondary School Leadership Class (research demonstrations)
2014-2018	Canadian Medical Hall of Fame Discovery Day (research demonstrations)
2015	Michael J. Fox Foundation Clinical Research Fair (research demonstrations)

Research and Teaching Employment

2017	**Research Consultant,** DataSense (Ont.)
2015-2016	**Research Assistant,** Avon Maitland District School Board (Ont.)

2014-2015 **Research Assistant, School of Occupational Therapy,** Western University
2013-2014 **Graduate Teaching Assistant,** Western University (Ont.)
2011-2013 **Teaching Assistant, Psychology Department,** St. Thomas University (NB)