The Effect of Step Length Instructions While Synchronizing Gait

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Abstract

Rhythmic auditory stimulation (RAS) is a method commonly used to regulate impaired gait (e.g., in Parkinson's Disease) by synchronizing footsteps with regularly occurring auditory cues. It is well-researched that incorporating perceived groove, beat perception ability, and instructions to synchronize into RAS can beneficially impact temporal gait outcomes including stride velocity. However, enhancements to spatial gait parameters such as stride length are not consistently observed. This is a crucial gap in the literature as without concurrent improvements in stride length, people with gait impairments remain susceptible to falls. The purpose of the present study was to address this gap by examining the effect of incorporating a new variable, step length instruction, to target stride length. Thirty-three healthy young adults, classified as good or poor beat perceivers, synchronized or free-walked to metronome and music cues that were high or low in levels of groove (how much the music induces the desire to move). Participants were instructed to maintain big steps in half the walking trials and received no step length instruction in the other half. The results revealed that step length instruction and auditory cue type indeed influenced participants' stride velocity and stride length. Additionally, during free-walking, good and poor beat perceivers responded differently to cue types. Here, I show that it is possible to target improvements in both stride velocity and stride length by shifting the user's attention to their step length with the proper task instructions. These results have important implications as better understanding the impact of step length instructions can provide insight for how to more effectively target impaired gait in clinical populations.

The Effect of Step Length Instructions While Synchronizing Gait

Parkinson's disease (PD) is one of the most common movement disorders in the world and is estimated to affect 1% of the population over the age of 60 (de Lau & Breteler, 2006; Tysnes & Storstein, 2017). Due to a deficit of dopamine in the basal ganglia of PD patients, the walking pattern of someone with PD differs from that of a healthy individual in a number of ways: shuffling of steps, slower walking speed, and instability. This impaired walking pattern observed in PD patients makes them especially susceptible to fall risk and injuries (Ashoori, Eagleman, & Jankovic, 2015; Dalla Bella, Dotov, Bardy, & Cock, 2018; de Bruin et al., 2010; Jankovic, 2008).

One rehabilitative method that has been shown to improve gait in PD patients is rhythmic auditory stimulation (RAS), which involves instructing participants to walk while synchronizing their steps to a stimulus such as a metronome or musical beats. Often RAS targets specific gait measures with the objective to decrease variability but increase both stride length and velocity. Factors that are often incorporated into RAS include groove (how much the music makes you want to move), beat perception ability, and instructions to synchronize footsteps to the beat. Previous studies have consistently found that incorporating groove and instructions to synchronize benefits gait velocity, however, there are still inconsistencies regarding benefits to stride length. The focus of the present study is to understand the conditions under which gait abnormalities can be improved through the use of RAS. In particular, the current study aims to explore the influence of step length instructions on gait in healthy young adults. Before introducing the current study, I first briefly present the existing literature on Parkinson's disease, followed by a description of the RAS method, and finally discuss the findings of studies investigating the effectiveness of RAS as a rehabilitative strategy.

Parkinson's Disease

Prevalence. Parkinson's disease is a common movement disorder and is the second most common neurodegenerative disorder, after Alzheimer's disease (Hirtz et al., 2007). The average age of onset is 60 (de Lau & Breteler, 2006), and thus, with the aging population, prevalence is expected to increase more than 50% by 2030 (Dorsey et al., 2007). Since PD affects a considerable amount of the population and there is no existing cure, it is important to understand how symptoms that interfere with daily functioning and quality of life, such as gait impairments, can be mitigated or managed.

Characteristics, symptoms, and implications. PD is characterized by loss of dopaminergic neurons in the substantia nigra (Kish, Shannak, & Hornykiewicz, 1988). This deficiency of dopamine results in impaired motor control, as the basal ganglia is implicated in a neural network responsible for initiating and executing sequential movements (Jankovic, 2008; Nombela, Hughes, Owen, & Grahn, 2013; Ruiz, Catalan, & Carril, 2011). A number of motor impairments can be observed in PD patients, including resting tremor, slowness of movement, and rigidity (Gelb, Oliver, & Gilman, 1999; Jankovic, 2008; Tysnes & Storstein, 2017). Another result of the deficient basal ganglia is impaired gait. The gait pattern observed in PD differs from that of healthy controls in a number of ways. Specifically, the gait pattern in PD is characterized by increased variability of gait, shuffling with shorter stride lengths, and reduced velocity (Morris, 2001). Gait impairments are one of the most debilitating symptoms of the disorder, often contributing to an increased risk of falls, subsequent injuries, and fear of falling (Ashoori et al., 2015; Dalla Bella et al., 2018; de Bruin et al., 2010; Jankovic, 2008). As a result, people with gait impairments experience lower levels of independence and functional mobility (McNeely, Duncn, & Earhart, 2012). Additionally, increased severity of PD is associated with reduced physical and social quality of life (Schrag, Jahanshahi, & Quinn, 2000). Together, these life-

altering implications of impaired gait and the increasing prevalence of PD have led to research of numerous treatment options for PD patients.

Recommended treatment strategies. Gait impairments are especially problematic for people living with PD because they are not easily managed with traditional pharmaceutical interventions. While medications, such as dopamine agonists and dopamine precursors, may help in initial disease stages, they do not effectively mitigate these symptoms long-term and eventually lead to further complications with prolonged usage (Fahn et al., 2014; Group, 2014; Hung & Schwarzchild, 2014). For this reason, alternative therapies have been proposed. One approach is the use of rhythmic auditory stimulation.

Rhythmic Auditory Stimulation

As previously noted, rhythmic auditory stimulation (RAS) is a gait rehabilitation method that involves the synchronization of steps to an auditory stimulus such as a metronome or musical beats. To address the slowness and instability seen in PD, RAS targets gait parameters such as velocity, stride length, stride width, double support time, and gait variability. For example, to promote speed, participants are often instructed to synchronize steps with an accelerated stimulus that is slightly faster than their normal walking rate. Studies have shown that the use of accelerated cues can be beneficial to increase velocity, however, it does not consistently result in increased stride length (Ghai, Ghai, & Effenberg, 2018a; Rubinstein, Giladi, & Hausdorff, 2002). Overall, synchronizing to auditory cues has been shown to improve a number of gait parameters including gait velocity, stride length, and gait variability (McIntosh, Brown, Rice, & Thaut, 1997; Nombela et al., 2013; Spaulding et al., 2013; Thaut et al., 1996). A suggested reason for the observed benefit of RAS on gait involves the nature of auditory stimuli.

Auditory and motor links. It is hypothesized that auditory stimuli are beneficial because rhythmic stimuli both activate the motor system and provide regular timing cues (Benoit et al,

2014; Nombela et al., 2013; Zatorre, 2007). This is crucial because the dopamine deficit in PD causes both perceptual and motor timing impairments (Jones, Malone, Dirnbergerm Edwards, & Jahanshahi, 2008). RAS may compensate for the deficient internal timing system by providing concrete auditory cues for when movements should occur (Benoit et al., 2014; Nombela et al, 2013; Thaut, McIntosh, & Hoemberg, 2015). Additionally, auditory stimuli are associated with increased activity in motor regions. More specifically, evidence from neuroimaging studies suggest that auditory stimuli activate alternative pathways in the brain that connect the auditory and motor systems but bypass the impaired basal ganglia (Eckert, Peschel, Heinze, & Rotte, 2006; Kotz & Schwartze, 2011; Lewis et al., 2007). Therefore, it appears that auditory stimuli may facilitate appropriate use of the motor system or alternative pathways that support regular controlled movement.

The existing literature has shown beneficial effects of both metronome beats and music on stride velocity and length (Ghai et al., 2018a; Ghai, Ghai, Schmitz, & Effenberg, 2018b). However, studies have shown that music may provide additional benefits in comparison to metronome. Specifically, music has been found to improve the emotional state of patients and increase motivation to walk (Blood & Zatorre, 2001; Dalla Bella et al, 2018; de Bruin et al., 2015; Terry, Karageorghis, Saha, & D'Auria, 2012). Moreover, listening to music has been shown to induce pleasure and activate reward systems in the brain, suggesting additional benefits of using music for clinical application (Blood & Zatorre, 2001). Finally, music has been shown to activate motor areas in the brain, and thus may play an important role in facilitating movement (Chen, Penhune, & Zatorre, 2008).

Variability in RAS outcomes. Despite a large body of research that report an overall effectiveness of RAS in both PD patients and healthy adults, meta-analyses indicate that RAS outcomes are variable (Ghai et al., 2018a; Ghai et al., 2018b; Spaulding et al., 2013). For

example, in a study by Dalla Bella et al. (2017), only half of the PD patients showed a positive gait response to RAS, while others exhibited either no effect or a worsened gait response. Some sources of variability in gait outcomes are more obvious, such as the pace of a cue (as faster or slower than baseline walking rate) or disease stage. On the other hand, there are also several perceptual, and somewhat individual, factors that have recently been found to impact outcomes. In particular, studies have found that the effectiveness of RAS may be dependent on individual factors such as beat perception ability and perception of music characteristics such as groove.

Beat perception and groove. A beat can be defined as a regularly recurring "perceived pulse" that is induced by a stimulus such as music (Nombela et al., 2013). It is well-known that the ability to perceive a beat varies across individuals (Grahn & Schuit, 2012; Phillips-Silver et al., 2011; Sowiński & Dalla Bella, 2013). Accordingly, beat perception ability may be a source of variability in gait outcomes when synchronizing to auditory stimuli. For example, it has been found that individuals who have trouble finding the beat also show difficulties with synchronizing to the beat in music (Phillips-Silver et al., 2011). Therefore, it may be beneficial to use auditory stimuli which have a clear beat so that poor beat perceivers can more easily find the beat and synchronize to it.

Another important variable is called groove, which is commonly described as how much a piece of music makes a person want to move. This property of music may affect gait patterns when synchronizing to music as groove has been associated with spontaneous movement and positive affect, which may lead to faster gait (Janata, Tomic, & Haberman, 2012). Further, high groove has been associated with greater beat salience (Janata et al., 2012; Madison, 2006), so it may be crucial for helping poor beat perceivers to find the beat. Specifically, high-groove music has been found to result in improved gait compared to low-groove music (Leow, Parrott, & Grahn, 2014; Leow, Rinchon, & Grahn, 2015). In a study by Leow et al. (2014), which

investigated beat perception and groove, it was found that gait performance was dependent on beat perception ability. Their results indicated that strong beat perceivers maintained or improved step length and velocity, but poor beat perceivers exhibited slower stride velocity and shorter step lengths compared to baseline (no music) walking. Additionally, participants' velocity and step lengths improved when walking to high-groove music compared to low-groove music. In comparison, participants took slower and shorter steps when listening to low-groove music compared to high-groove music (Leow et al., 2014).

It is clear that the beneficial outcomes of the RAS method are dependent on a number of factors such as individual beat perception abilities and music properties such as groove. Another variable that has been well-explored is instructions to synchronize.

Instructions to synchronize. RAS is often based on the idea that intentionally synchronizing to the beat of an auditory stimulus is what leads to gait outcomes (Ashoori et al., 2015; Nombela et al., 2013; Thaut et al., 2015). As a result, when researchers provide explicit instructions to synchronize, beneficial gait outcomes have been found in the form of stride length increases, faster stride velocity, and less variable gait (Leow et al., 2015; Baker, Rochester, & Nieuwboer, 2007; Lohnes & Earhart, 2011; Nieuwboer et al., 2007; Rochester et al., 2005). However, what's interesting is that a number of RAS studies have found beneficial effects in the absence of any instructions to synchronize (Benoit et al., 2014; de Bruin et al., 2015). These results suggest that providing instructions to synchronize to the beat may not be necessary to improve gait and some authors suggest that people may naturally synchronize without instruction (Leow, Waclawik, & Grahn, 2018).

Yet, studies comparing synchronizing versus free walking indicate that intention to synchronize does seem to significantly enhance gait changes. Often, intention to synchronize is manipulated through instructions to synchronize, with one group being given instructions to

match their footsteps to the beat, while another group receives no instruction to synchronize ("walk freely"). Previous studies investigating the impact of synchronization have found that instructions to synchronize resulted in faster velocity but smaller step lengths, compared to uninstructed conditions (Leow et al., 2018; Nessler & Gilliland, 2010). In line with this, a series of studies found that instructions to synchronize tended to improve gait parameters in both young adults and PD patients compared to free-walking (Ready, 2019a). Among young adults and PD patients, participants who synchronized demonstrated faster velocity compared to uninstructed participants. Despite benefits to stride velocity, step length did not change based on instruction condition for young adults and PD patients alike.

Together, these studies demonstrate that instructing participants to synchronize does in fact influence the gait pattern positively by increasing stride velocity. However, it is still uncertain as to how stride length can be increased in addition to increased velocity. Due to the proven benefits of faster gait velocity as a result of instructions to synchronize, this variable will be included in the present study.

Even among other RAS studies, gait outcomes have been variable, with benefits often being observed in only certain gait parameters. In parallel to the previous instructions to synchronize studies, a number of studies have found gait benefits in terms of faster gait velocity; but studies do not reliably produce increases in stride length (Lim et al., 2005). Although increases in velocity may appear to be beneficial, without a simultaneous improvement in stride length, the shuffling gait pattern may still be observed in PD patients, making them susceptible to falling (Morris, Iansek, Matyas, & Summers, 1994; Morris, Iansek, Matyas, & Summers, 1996). This observation that gait velocity but not stride length often improve as a result of RAS, highlights a crucial gap in the literature. Therefore, the present study aims to address this gap by introducing a new variable to target stride length.

Previously, two studies found that incorporating instructions to take larger steps was associated with increases in both gait velocity and stride length (Baker et al., 2007; Lohnes and Earhart, 2011). However, no studies to date have assessed the influence of this factor in combination with previously mentioned variables of beat perception, groove, and instructions to synchronize.

The Present Study

Although there is a well-documented benefit of using RAS to improve gait, there is still a question of how to increase stride length while maintaining benefits to other gait parameters. The present study aims to bridge this gap by addressing the question of how to facilitate increases in stride length during RAS. To target the issue of stride length, a new variable, step length instruction, will be incorporated to assess whether it influences the gait pattern. I aim to explore the impact of this new variable by instructing participants to maintain big steps in half of the walking trials and providing no instructions to maintain big steps in the other half of walking trials. Based on previous work indicating that beat perception ability and perceived groove impact gait outcomes during synchronized and free-walking RAS, I will look at how incorporating step length instruction in combination with these variables will affect the gait pattern, specifically, step velocity and stride length. The current study contributes to the literature by exploring the impact of these four factors in healthy young adults. Participants will be randomly assigned to either a synchronize or free-walk group and will walk to high groove songs, low groove songs, and metronomes once without step length instruction and once with step length instructions. Beat perception will be determined by a median split of scores on the Beat Alignment Test. Based on the findings of previous studies, is hypothesized that stride length will be largest with instructions to synchronize and instructed step lengths when listening to high groove songs, among good beat perceivers. Additionally, it is expected that for all cueing types,

providing step length instruction will facilitate larger stride lengths compared to when no step length instructions are provided. Finally, it is expected that high groove music will elicit faster velocity than low groove music in both synchronizing and free-walking conditions.

Method

Participants

Thirty-four undergraduate students were recruited from Western University (see Table 1 for demographic information). One participant was excluded due to a technical error (computer malfunction). Additionally, one participant completed six passes of the walkway (instead of eight) in one trial due to a technical error, but this data was still included. The final sample consisted of 33 participants. (24 females; M_{age} = 18.21, SD_{age} = 0.55). Individuals were eligible to participate if they had normal hearing and did not have neurological problems. Participants provided informed written consent and were compensated with 1.5 course credits. The study was approved by Western University's NonMedical Research Ethics Board (Appendix A).

Table 1

Participant Demographics by Condition

	Free-Waking		Synchronizing	
	Good BP (n = 9)	Poor BP (n = 9)	Good BP (n = 5)	Poor BP (n = 10)
Age	18.33 (0.71)	18.33 (0.71)	18.00 (0.00)	18.10 (0.32)
Female/Male	8/1	5/4	4/1	7/3
Right Handed/Left	9/0	8/1	5/0	9/1
Music Training	8.78 (5.04)	5.83 (3.97)	7.10 (4.34)	5.00 (4.17)
Dance Training	6.50 (3.54)	3.00 (4.05)	8.00 (3.16)	7.70 (5.40)

Note: Data presented as means (standard deviations) for age, music training, and dance training. Sums are presented for sex and handedness. Age, music training, and dance training are expressed in years.

Materials

Pressure sensor walkway. A 16-foot long Zeno™ pressure sensitive walkway was used to measure dependent variables of stride length (cm), stride velocity (cm/s), and cadence (steps per minute). Stride length was measured as the distance between the heel contact of one foot to the heel contact of the successive (ipsilateral) step. Velocity was measured by dividing stride length (cm) by the time to complete that stride (s). ProtoKinetics Movement Analysis Software Package (PKMAS; ProtoKinetics LLC, Havertown, PA) was used to process and calculate these measures; data were verified by the experimenter.

Auditory stimuli. Participants rated 13 previously piloted music clips (instrumental versions) for familiarity and groove to determine which auditory stimuli to use in the later walking task (for a complete list of songs, see Appendix B). Stimuli were piloted to verify levels of groove and familiarity that are typically perceived by a similar age group. However, use of the ratings task verified which songs an individual participant perceived as being high groove and low groove. The 13 clips were modified to a tempo (beats per minute) of 10% faster than the participants' baseline cadence (steps per minute) using Audacity Sound Editing Software. Presenting accelerated stimuli at a pace of 10% faster than baseline has been previously found to be associated with increases in velocity (Ghai et al., 2018a). The ratings task was presented via LabVIEW (National Instruments, Austin, TX) and participants listened to the music clips in a randomized order over Bose QuietComfort 3 headphones. Participant ratings were used to select a tailored set of eight songs for the walking tasks (described under "Procedures"). A metronome

was also used during participants' walking trials and was set to a tempo of 10% faster than a participants' baseline cadence. During the walking trials, stimuli were played at a comfortable volume using wireless headphones (Sennheiser® HDR 160) to prevent experimenter influence and were presented in a randomized order.

Beat Alignment Test. The Beat Alignment Test (BAT) from the Goldsmiths Musical Sophistication Index v1.0 (Müllensiefen, Gingras, Stewart, & Musil, 2012) was used to measure participants' beat perception ability. BAT stimuli were presented through headphones (Bose QuietComfort 3) to prevent experimenter influence.

Demographics and music training questionnaire. A questionnaire was administered to participants to collect demographic information, music training, and dance training information, based on questions used in a similar study (Ready, 2019a). The questionnaire was presented on Qualtrics (Qualtrics, 2019) and was completed electronically during the experiment (see Appendix C and D for full list of questions).

Procedures

Upon arrival, participants received a letter of information and provided informed consent (Appendix E). Participants then completed a baseline walk in silence on the pressure sensitive walkway for one trial (1 trial = walking eight consecutive lengths of walkway) to record their baseline gait measures. Prior to this, participants were instructed to "walk however feels normal to you" and completed a one-minute practice trial (unrecorded), giving them the opportunity to find their normal walking pace. To remain in constant motion (reducing capture of acceleration/deceleration effects), participants walked continuously between two black lines located 1.78 meters from each end of the mat and were asked to complete a loop to turn after reaching each line (see Figure 1 for a visual of the walkway).

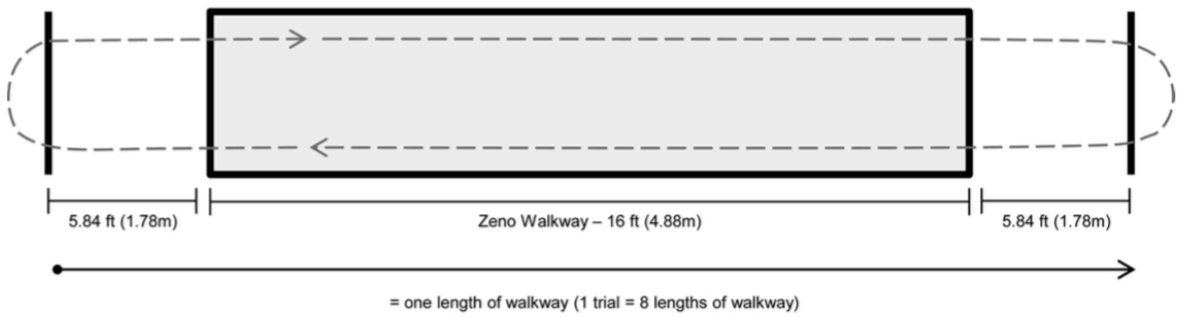

Figure 1. Pressure sensitive walkway used for walking trials (Ready, McGarry, Rinchon, Holmes, & Grahn, 2019b)

Rating task. Each participants' baseline cadence, as calculated in PKMAS, was used to determine the appropriate tempo of auditory stimuli for both the rating and cued walking tasks. Stimuli were played at a rate 10% faster (in beats per minute) than each participant's baseline cadence (steps per minute). Participants first completed the rating task wherein they listened to the 13-song database (see materials) of 30 second music clips and rated each music clip on four items: familiarity, groove, enjoyment, and beat salience. Each item was rated on a 100-point Likert scale (see Table 2 for end anchors). High groove was operationalized as ratings above 50, while low groove was operationalized as ratings below 50. Low familiarity ratings (ratings under 50), were used to control for potential effects of familiarity on participants' walking. Ratings for enjoyment and beat salience were included as filler items and were not analyzed.

Table 2

End anchors for rating scales (Ready et al., 2019b).

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 = I strongly dislike this song 100 = I strongly enjoy this song

Beat Salience: "How strong is the beat in this piece of music to you?"

1 = Very weak 100 = Very strong

Cued walking trials. Four songs rated as high groove and four songs rated as low groove, all with low familiarity, were selected for the cued walking trials using a custom written MATLAB script. Cued walking trials were completed in two sets: instructed step length (instructed to maintain big steps) or uninstructed step length (no instruction about step length). The order of step length instructions was counterbalanced across participants. In each set of walks, participants completed six cued walking trials: two low groove, two high groove, and two metronome; trials were completed in a randomized order. Prior to the experiment, participants were randomized to one of two synchronization instruction conditions: synchronize (match footsteps to the beat) or free-walk (walk comfortably with music in the background) and completed all walks in their assigned condition. Thus, regardless of synchronization condition, all participants walked to stimuli that were high and low in groove both with and without instructions to maintain big steps.

Practice trials and baseline trials. Practice trials and silent walking trials were also used in the experiment. Regardless of synchronization condition, all participants completed two practice trials prior to the first set of cued trials; practice trials used two music clips (one high and one low groove) not used in any other portion of the study. This provided participants the opportunity to practice walking with their assigned synchronization instruction and the

experimenter an opportunity to confirm instructions were understood. In addition, participants completed a second silent (baseline) walking trial between the first and second set of cued trials. As with the initial baseline trial, participants completed one-minute of silent and unrecorded walking to find their comfortable or natural walking rate prior to beginning baseline recording.

Questionnaire. Participants completed the demographic questionnaire in two parts. Part one addressed sex, handedness, and age and was completed immediately after the first set of cued walks. Part two addressed dance and music training and was completed at the end of the experiment.

Beat Alignment Test (BAT). Lastly, participants completed the Perception Subtest of the BAT to quantify beat perception ability. Participants heard 17 instrumental music clips with superimposed beeps and made judgements about whether the beeps were on or off the beat without tapping or moving to find the beat. Participants indicated their answers on a keyboard by pressing the 'Y' key to indicate yes (on the beat) or the 'N' key for no (off the beat). Finally, participants rated their confidence in their decision by responding with 1 (*guessing*), 2 (*somewhat sure*), or 3 (*completely certain*). Percentage accuracy on the BAT has been used in previous studies (Leow et al., 2014; Ready, 2019a; Ready et al., 2019b) to classify participants as either good or poor beat perceivers. Following the completion of the study, participants received a debriefing form at which point they were given the opportunity to ask any questions (Appendix F). The experiment took approximately 1.5 hours to complete. For a visual of the entire procedure, see Figure 2.

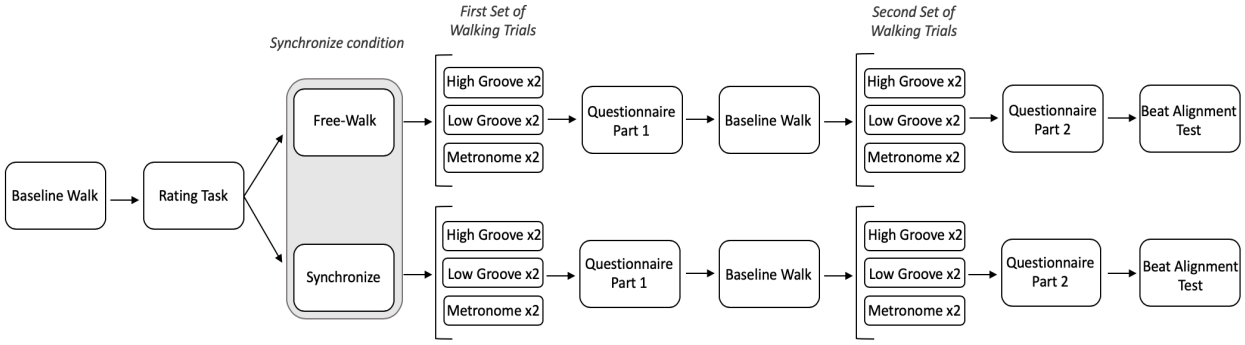

Figure 2. Full study procedure. Grey shaded area indicates between-subjects randomization into one of two synchronization instruction conditions. Two sets of cued walking trials were completed in which participants were instructed on step length in one set and uninstructed on step length in the other set.

Data Analysis

Gait Parameters. Walking trials were individually processed through PKMAS and all footsteps less than ¾ of the participant's average foot size (which occurred when participants stepped on and off the mat) were excluded from analyses. A custom-written MATLAB script was used to calculate average gait parameters (stride length and stride velocity) from each walking trial.

Beat Alignment Test Scores. BAT perception scores were calculated as a percentage of trials correct out of 17 trials. Accuracy scores on the BAT ranged from 0.47 to 1 (M = 0.72, SD = 0.15). A median split was used to classify participants as good beat perceivers (scores above 0.72) and poor beat perceivers (scores equal to or below 0.72), consistent with previous studies (Leow et al., 2014).

Statistical Analysis. Each dependent variable was analyzed in a separate four-way mixed-design analysis of variance (ANOVA) using the Statistical Package for the Social

Sciences (SPSS) version 26. Between-subject variables were instructions to synchronize (synchronize = match footsteps with the beat, free-walk = walk comfortably) and beat perception ability (good, poor). Within-subject variables included cue type (high groove music, low groove music, metronome) and step length instruction (instructed step length = maintain big steps, uninstructed step length = no instruction for step length). Greenhouse-Geisser corrected values are reported when Mauchly's test of sphericity is significant to adjust for violations of the assumption of sphericity.

Normalization. Analyses were conducted on normalized change scores to account for individual differences in gait (e.g. differences in leg length, hip width). Normalized change scores represented the proportion of change from baseline gait. This was calculated by subtracting the baseline gait parameter (e.g. stride length or velocity in silence) from the cued gait parameter (e.g. stride length or velocity in high groove, low groove, or metronome conditions) and then dividing by the baseline gait parameter:

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

Results for all gait parameters are reported as the proportion of change from baseline.

Results

Stride Length (centimeters)

A 4-way mixed-design ANOVA revealed a significant main effect of cue type [$F(1.34, 38.70) = 30.10$, $p < .001$, $\eta^2 = .51$]. Participants took significantly larger strides with high groove cues ($M = .053$, $SD = .012$) versus low groove cues ($M = .021$, $SD = .012$) and metronome ($M = .028$, $SD = .012$). Stride length was significantly larger with metronome cues than observed with low groove cues (see Table 3 for descriptive statistics). Additionally, a significant main effect of step length instruction [$F(1, 29) = 7.00$, $p = .013$, $\eta^2 = .19$] indicated participants took significantly larger strides when instructed on step length ($M = .049$, $SD = .014$) than observed

when uninstructed on step length (M = .019, SD = .012). A significant cue type by step length instruction interaction was present [$F(1.75, 50.81) = 3.85$, $p = .033$, $\eta^2 = .12$] (Figure 3A). As an interaction was found, main effects of cue type and step length instructions should be interpreted with caution. Follow-up t-tests revealed that participants lengthen strides significantly more when instructed on step length than when uninstructed on step length across all cue types; however, the pattern across cue types is influenced by step length instructions. Additional follow-up t-rests revealed no significant difference that identified the source of the interaction (see Appendix H for statistics). Therefore, the interaction must be interpreted with caution.

Finally, a significant main effect of beat perception was also observed [$F(1, 29) = 6.70$, $p = .015$, $\eta^2 = .19$]. Good beat perceivers (M = .064, SD = .018) took significantly larger strides than poor beat perceivers (M = .004, SD = .015).

Table 3

Raw Means and Standard Deviations of Gait Parameters for Each Cueing Condition

	Free-Waking		Synchronizing	
	Good BP (n = 9)	Poor BP (n = 9)	Good BP (n = 5)	Poor BP (n = 10)
Stride Length (cm)				
Baseline	113.89 (3.78)	120.52 (4.37)	108.97 (5.82)	113.27 (3.69)
Instructed Step Length				
High Groove	130.93 (4.08)	128.97 (3.86)	125.60 (3.16)	119.30 (4.59)
Low Groove	118.36 (4.10)	123.31 (3.67)	117.55 (3.31)	108.68 (5.05)
Metronome	127.08 (3.98)	126.05 (3.50)	123.85 (2.92)	117.39 (4.43)
Uninstructed Step Length				
High Groove	125.84 (3.19)	128.41 (3.57)	126.14 (3.29)	118.73 (4.40)

Low Groove	114.20 (3.90)	122.09 (3.53)	120.63 (2.94)	110.73 (4.41)
Metronome	121.15 (2.92)	125.24 (3.48)	124.32 (3.45)	117.99 (4.41)
Stride Velocity (cm/s)				
Baseline	113.89 (4.90)	120.52 (5.89)	108.97 (6.89)	113.27 (4.33)
Instructed Step Length				
High Groove	130.93 (4.18)	128.97 (4.56)	125.60 (3.08)	119.30 (4.62)
Low Groove	118.36 (4.02)	123.31 (4.31)	117.55 (3.55)	108.68 (5.23)
Metronome	127.08 (4.23)	126.05 (4.04)	123.85 (2.95)	117.39 (4.10)
Uninstructed Step Length				
High Groove	125.84 (3.55)	128.41 (4.26)	126.14 (3.73)	118.73 (4.51)
Low Groove	114.20 (3.59)	122.09 (4.30)	120.63 (3.41)	110.73 (4.69)
Metronome	121.15 (3.59)	125.24 (4.05)	124.32 (3.47)	117.99 (4.37)

Note. BP = beat perception.

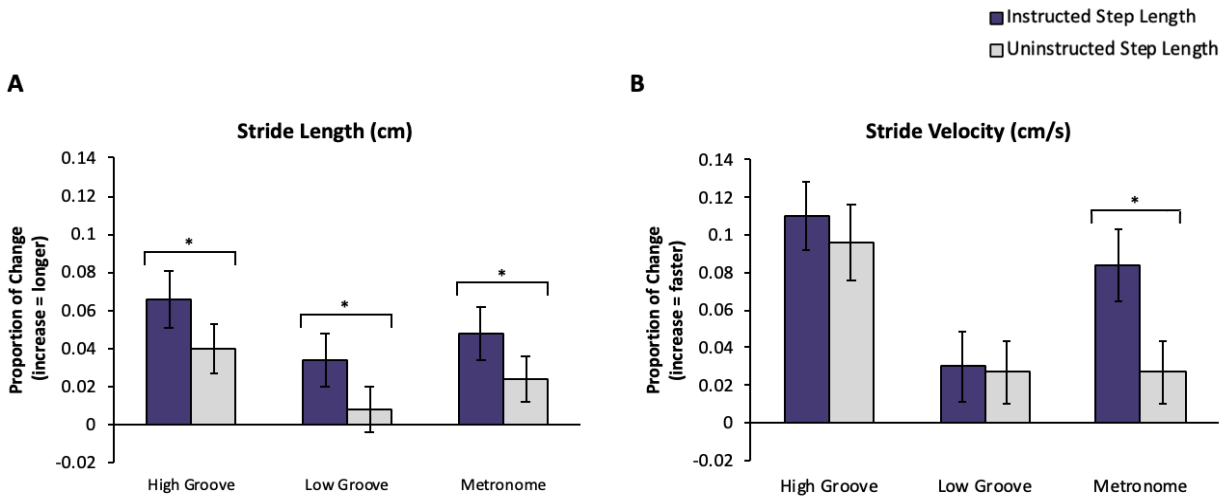

Figure 3. Normalized change scores (proportion of change from baseline) for the effects of step length instruction and cue type on gait parameters. Zero represents baseline. Thus, values close to zero indicate similar gait to baseline, while values increasing from zero indicate increases compared to baseline. (**A**) Mixed-design ANOVAs indicate significantly larger strides when

instructed on step length versus uninstructed on step length across all three cue types, and (**B**) significantly faster velocity when instructed on step length versus uninstructed on step length for metronome only cues. *$p < .05$.

Stride Velocity (centimeters/second)

A significant main effect of cue type [$F(1.50, 43.40) = 48.39$, $p < .001$, $\eta^2 = .63$] indicated that high groove cues ($M = .103$, $SD = .018$) elicited significantly faster stride velocity than low groove ($M = .028$, $SD = .017$) and metronome cues ($M = .056$, $SD = .017$). Faster velocity was also observed with metronome cues compared to low groove cues. A significant main effect of step length instruction was also found [$F(1, 29) = 5.29$, $p = .029$, $\eta^2 = .15$]. Stride velocity was significantly faster when instructed on step length ($M = .075$, $SD = .018$) compared to when uninstructed on step length ($M = .050$, $SD = .018$). These main effects were qualified by a significant interaction between cue type and step length instruction [$F(1.90, 55.04) = 14.09$, $p < .001$, $\eta^2 = .33$] (Figure 3B). As an interaction was found, main effects of cue type and step length instructions should be interpreted with caution. Follow-up t-tests indicated that participants' velocity was significantly faster when instructed on step length than when uninstructed on step length when cued with metronomes [$t(32) = 4.74$, $p < .001$], but no differences were found between step length instruction conditions for high groove or low groove cues [High Groove: $t(32) = 1.32$, $p = .197$; Low Groove: $t(32) = 0.48$, $p = .623$]. A significant main effect of beat perception [$F(1, 29) = 4.33$, $p = .046$, $\eta^2 = .13$] indicated that good beat perceivers ($M = .097$, $SD = .026$) walked with significantly faster velocity compared to poor beat perceivers ($M = .027$, $SD = .021$). This was qualified by a significant three-way interaction between cue type, synchronization, and beat perception [$F(1.50, 43.40) = 4.11$, $p = .033$, $\eta^2 = .12$] (Figure 4). Follow up t-tests were completed to examine simple main effects and revealed that during free-

walking, good beat perceivers show significantly faster velocity when walking to metronome cues compared to low groove cues [$t(8) = -3.33$, $p = .010$]. In contrast, poor beat perceivers show no differences in velocity between low groove and metronome cues [$t(8) = -1.48$, $p > .05$]. When synchronizing, both good and poor beat perceivers walk significantly faster with high groove cues compared to low groove cues [Good: $t(4) = 3.71$, $p = .021$; Poor: $t(9) = 3.73$, $p = .005$]. Similarly, both groups demonstrate faster velocity with metronome compared to low groove cues [Good: $t(4) = -3.17$, $p = .034$; Poor: $t(9) = -3.80$, $p = .004$]. However, during synchronized walking, good beat perceivers walk with overall faster velocity than poor beat perceivers across all cueing conditions.

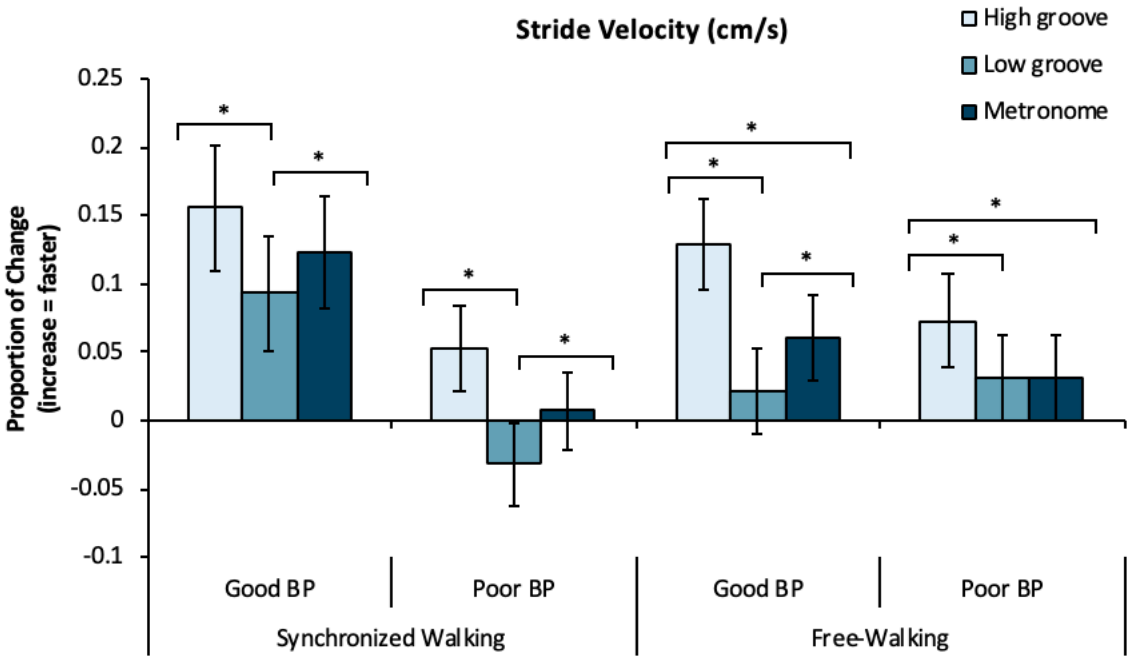

Figure 4. Normalized change scores (proportion of change from baseline) for the effects of synchronization instructions, beat perception ability, and cue type on velocity. Zero represents baseline. Thus, values close to zero indicate similar gait to baseline, while values increasing from zero indicate increases compared to baseline. Mixed-design ANOVAs indicate significant differences between high groove, low groove, and metronome cues among both good and poor

beat perceivers when synchronizing. When free walking, good beat perceivers show significant differences in velocity with high groove cues compared to low groove and metronome cues. In contrast, poor beat perceivers walked with similar velocity with metronome and low groove cues. Poor beat perceivers walked significantly faster with high groove cues compared to low groove and metronome cues. BP = beat perception. *$p < .05$.

Discussion

The purpose of the present study was to investigate how step length instruction, instructions to synchronize, and individual beat perception ability influenced the gait pattern of healthy young adults during RAS when walking to high groove music, low groove music, and metronomes. As expected, based on previous work with accelerated RAS, faster velocity was observed across several conditions with cueing at 10% faster than baseline. Importantly, whether velocity increased from baseline appeared to depend on factors of cue type, beat perception ability, and synchronization. In line with my hypotheses, a crucial component of increasing or maintaining step length during accelerated RAS was providing instructions about step length.

It was hypothesized that step length would be largest with instructions to synchronize and instructed step lengths when listening to high groove songs, among good beat perceivers. Contrary to my hypothesis, there was no evidence of this four-way interaction. However, significant findings supported my expectation that providing step length instruction would elicit larger strides compared to no step length instruction. Specifically, instructed step lengths led to larger stride lengths compared to uninstructed step lengths in all cueing conditions. Additionally, instructed step lengths elicited faster velocity compared to uninstructed step lengths with metronome cueing. Finally, there was evidence of an interaction involving instructions to synchronize, beat perception, and cue type, where good beat perceivers had significantly faster

velocity with metronome cues compared to low groove music during free-walking, but poor beat perceivers showed no differences in velocity when cued with metronome and low groove music.

Importantly, these findings suggest that incorporating step length instructions can successfully shift the participant's focus from being primarily on gait speed, to enhancing both speed and stride length. This has implications for RAS because it may provide alternative ways of presenting RAS that promotes improvements in compromised gait symptoms.

Participants Lengthen Strides with Appropriate Instructions and Stimuli

Overall, instructing participants to maintain their step length elicited more favourable gait changes than was observed without this instruction. Specifically, participants demonstrated significantly larger strides and faster gait velocity with this instruction relative to what was observed when no instructions were provided regarding step length. This is consistent with my hypothesis that step length instruction would produce larger strides for all cueing types.

As shortened strides are a major characteristic of impaired gait (Morris et al., 1996), the aim of gait rehabilitation methods is to not only improve gait speed and stability, but stride length as well. A large limitation of previous work is that RAS has often emphasized the temporal aspects of cueing (e.g., asking participants to match steps in time with the music), which might suggest to users that timing aspects are the priority. Additionally, existing research has found that by increasing cue tempo (providing accelerated cues) we can successfully target increases in velocity. However, in previous studies with accelerated RAS, users typically only maintain or significantly shorten their step length from baseline when synchronizing and free walking with RAS (Hausdorff, Lowenthal, Gruendlinger, Peretz, & Giladi, 2007; Leow et al., 2014; Ready et al., 2019b; Willems et al., 2006). Thus, users appear to prioritize adjustments in gait speed through faster stepping rate (i.e., step time, cadence) at the cost of step length. These results seem to suggest that step length cannot be improved with accelerated cues. However, the

findings of the present study demonstrate this is not the case and that it is possible for participants to enhance step length during accelerated RAS. Simply shifting the attention of the participant toward their step length, by requesting they maintain step length and without imposing a difficult task of increasing step length, was enough to achieve the desired increases in step length. It is likely that shifting participants' focus to step length led to them prioritizing adjustments for this spatial parameter.

Additionally, the finding that step length instructions elicited faster velocity relative to uninstructed step length, but only for metronome cues is inconsistent with previous results that high groove cues elicit similar or better gait outcomes than metronome (Leow et al., 2014; Leow et al., 2015; Styns, van Noorden, Moelants, & Leman, 2007; Wittwer et al., 2013). This inconsistent finding may be due to the high beat salience of metronomes and the added cognitive demands of providing step length instructions. Firstly, it is possible that participants respond differently to musical properties of groove and beat salience, as suggested by Ready et al. (2019b). Previous studies that found high groove music elicits similar or better outcomes than metronome did not involve the added step length instructions. As music has been found increase cognitive demands (Brown & Marsden, 1991), it is possible that the addition of step length instruction further increased those demands during RAS. Under these dual-task conditions, it is possible that participants are more responsive to musical properties of beat salience than groove or that attending to groove creates greater cognitive demands. As metronomes have higher beat salience than music (Leow et al., 2014; Levitin & Cook, 1996), they may make it easier to pick out the beat and make appropriate adjustments in velocity to keep up with the accelerated tempo.

Instructions to Synchronize or Free-Walk Impact Good and Poor Perceivers Differently

The findings from this study support that beat perception ability may influence outcomes with RAS, and that these effects are influenced by both cue type and whether participants are

synchronizing with the beat. While synchronizing, poor beat perceivers demonstrated an overall slower velocity, regardless of cue type, when compared to good beat perceivers. Importantly, although poor beat perceivers were slower than good beat perceivers while synchronizing, they demonstrated a similar pattern where velocity was fastest with high groove and metronome cues compared to low groove cues. These results are consistent with Leow et al. (2014) who found that high groove and metronome cues produce comparable results while synchronizing. In contrast, good and poor beat perceivers demonstrated distinct patterns of change across cue types while free-walking. Poor beat perceivers demonstrated faster velocity with high groove cues compared to both metronome and low groove cues, with the latter two being statistically similar. However, good beat perceivers' velocity significantly differed among all cue conditions (fastest velocity with high groove, slowest velocity with low groove). The finding that high groove music elicited faster velocity than metronome and low groove cues is consistent with previous findings (Ready et al., 2019b; Wittwer et al., 2013).

In general, the difference between good and poor beat perceivers while synchronizing may represent dual-task interference. This is a phenomenon where engaging in or attending to a cognitively demanding task while walking can cause slower and shorter strides (O'Shea, Morris, & Iansek, 2002; Heinzel et al., 2016). This finding is consistent with previous studies suggesting that poor beat perception ability creates dual-task interference while synchronizing (Leow et al., 2014; Leow et al., 2015). Therefore, it is possible that for poor beat perceivers, synchronizing their steps to an auditory beat may be a more attentionally demanding task than for good beat perceivers, affecting their ability to perform on the task.

An alternative possibility is that poor beat perceivers walked without synchronizing. Poor beat perceivers' velocity was similar to baseline, which might imply that poor beat perceivers walked normally and disregarded the instructions to synchronize to the accelerated auditory cues.

Furthermore, the existing literature has reported inconsistencies with regards to the effect of synchronizing on gait outcomes. While some studies have reported that synchronizing elicits slower velocity and shorter strides (Leow et al., 2018), others have found increased velocity without improvement in stride length (Leow et al., 2014; Leow et al., 2015; Lohnes & Earhart, 2011). The present study supports that emphasizing stride length may facilitate increases in velocity and step length concurrently during high groove cueing, but this may not be the case for poor beat perceivers while synchronizing. Thus, instructions to synchronize may differentially affect the velocity of good and poor beat perceivers, depending on the type of cue presented.

Future Directions and Limitations

The current study looked at healthy young adults with no pathological gait impairments. PD patients may respond differently to RAS as they experience limitations in their muscle activation patterns, show shortened strides, and increased instability (Ebersbach, Moreau, Gandor, Defebvre, & Devos, 2013). While previous studies have found that RAS produces similar gait outcomes for PD patients and healthy adults, PD patients tend to benefit at a larger magnitude, potentially due to ceiling effects for healthy controls who already have normal gait (Dalla Bella et al., 2017; Dalla Bella et al., 2018; Ready, 2019a). Given differences in the magnitude of results, it is difficult to know with certainty if PD patients will respond in the same way as healthy young adults with the addition of step length instructions. It is also possible that introducing step length instructions may impact PD patients differently due to dual-tasking. Previous literature has shown that PD patients are at higher risk for to dual-task interference than healthy adults (Brown, de Bruin, Doan, Suchowersky, & Hu, 2009; O'Shea et al., 2002; Yogev et al., 2005). As a result, they may experience more difficulties with the incorporation of step length instructions compared to healthy young adults, which may affect their gait outcomes. Although the results of the present study cannot generalize to people with PD, understanding

how these factors influence gait in healthy populations is a crucial step in understanding the ordinary effect of synchronizing, step length instructions, beat perception, and groove on gait. However, we cannot assume the same outcomes in a healthy group and need to gradually address this before recommendations can be made for altered therapeutic approaches.

Furthermore, RAS interventions are targeted at people with gait impairments who are at high fall risk, primarily in PD (in which we see elevated gait variability). How these RAS techniques impacted stability was not assessed in the present study. As stability is an important concern, future studies should examine the effect of step length instruction on other dependent variables. Doing so will be important to identify whether these improvements in stride velocity and step length compromise equally important gait parameters such as balance and variability.

The present study consisted of a single session per participant, and practice trials were only provided before the first set of walks. Crucially, a study investigating dual-tasking during RAS found that the effects of dual-taking subside over time as participants receive more practice with the task (de Bruin et al., 2015). It is possible that asking participants to synchronize may have interfered with the first few walking trials. However, participants' progression through trials was not examined, thus conclusions cannot be made about whether any potential dual-tasking effects observed would subside over time, with practice. Additionally, when participants were uninstructed on step length on the first set of walks transitioned to the instructed step length condition, they may require practice to adjust to the new instructions. Future studies may find it useful to provide participants with practice trials after the new instructions are given (for the second set of walks) to limit effects of dual-tasking. This may allow participants to adjust and become familiar with the task to ensure that recorded walks can measure the actual effects of the instructions. Alternatively, a pre-post design such as de Bruin et al.'s (2015) could help to better understand this in good and poor beat perceivers with practice.

Finally, a small sample size obtained in the present study. This may have impacted my ability to detect differences with smaller effect sizes and may limit the generalizability of findings to the general population.

Conclusion

To date, researchers have consistently identified that accelerated RAS can successfully improve temporal gait parameters such as stride velocity, but this often has either no effect or comes at the cost of spatial parameters such as stride length. This remains a major challenge to implementing RAS in clinical populations due to the fall-risk associated with low ground clearance and decreased stride length observed in PD. The present study examined how increasing attention to step length can alter stride length and speed by examining the effect of altered task instructions in good and poor beat perceivers while synchronizing and free-walking to stimuli ranging in groove. Findings support previous work suggesting that high groove cues produce optimal outcomes, sometimes comparable or better than metronome. The findings also support that good and poor beat perceivers may not respond to synchronization instructions similarly and thus may require individualized approaches. Most importantly, the results of the present study support that we can in fact promote increased, not just maintained, step length during accelerated cueing across both synchronized walking and free-walking groups. While these results were observed in a healthy group, this suggests that with the proper task instructions, it may be possible to target both spatial and temporal parameters with the same accelerated cueing approach. Once the effect of task instructions is better understood in clinical groups, this may provide valuable contribution for how to better target all problematic gait symptoms with RAS instead of only half the problem.

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Appendix A: Ethics Approval

Western Research

Date: 5 February 2019

To: Dr. Jessica Grahn

Project ID: 104487

Study Title: Walking at different speeds

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Meeting Date: 01/Mar/2019

Date Approval Issued: 05/Feb/2019

REB Approval Expiry Date: 01/Mar/2020

Dear Dr. Jessica Grahn,

The Western University Non-Medical Research Ethics Board has reviewed this 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.

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.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Daniel Wyzynski, Research Ethics Coordinator, on behalf of Prof. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Appendix B: List of Songs Used as Stimuli

Song Title	Piloted Category
Bar Music	LFHG
Candy Rock	LFHG
Gayrigg	LFHG
King Charles	LFHG
Notes	LFHG
Ol Country	LFHG
Zumba Latina	LFHG
A Walk	LFLG
Cain and Abel	LFLG
Colorado	LFLG
Everything You Do Is A Balloon	LFLG
Lullaby	LFLG
White Keys Chilly Gonzales	LFLG

Note. The stimuli were taken from a database of music previously piloted and rated by individuals of a similar age group as being high or low groove and low familiarity. LFHG denotes songs categorized as low familiarity high groove and LFLG denotes low familiarity low groove songs.

Appendix C: Part One of Questionnaire

FOR THE EXPERIMENTER: Enter the study participant number (e.g., FREE-001).

What is your SONA ID (your six digit identifier on SONA)?

What is your dominant hand?

- Right
- Left
- Ambidextrous

Do you have normal hearing?

- Yes
- No

Display This Question:
If Do you have normal hearing? No Is Selected

If you indicated that you do not have normal hearing, please elaborate:

Do you have normal vision? (e.g. don't need glasses, contacts, don't have cataracts, etc.)

- ○ Yes
- ○ No

Display This Question:

If Do you have normal vision? (e.g. don't need glasses, contacts, don't have cataracts, etc.) No Is Selected

If you indicated that you do not have normal vision, please elaborate:
(e.g., wear reading glasses, cataract, etc.)

What is your age?

Display This Question:

If Do you have normal vision? (e.g. don't need glasses, contacts, don't have cataracts, etc.) No Is Selected

If you indicated that you do not have normal vision, please elaborate:
(e.g., wear reading glasses, cataract, etc.)

What is your age?

What is your sex?

- ○ Male
- ○ Female
- ○ Other

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
- ○ No

Display This Question:

If Do you take any psychotropic drugs, either recreationally or medicinally? Psychotropic drugs: one... Yes Is Selected

If you indicated that you take psychotropic drugs, please describe:

Do you have any psychiatric or neurological conditions?

- ○ Yes
- ○ No

Do you have any physical health conditions that impact your walking or balance?

- ○ Yes
- ○ No

Display This Question:

If Do you have any physical health conditions that impact your walking or balance? Yes Is Selected

If you indicated yes to the question above, please elaborate:

Do you listen to music when you walk?

- Yes
- Sometimes
- No

How many years of education do you have?

- Did not graduate high school
- Completed high school
- Enrolled in or completed undergraduate or college education
- Enrolled in or completed graduate education
- Other:

Appendix D: Part Two of Questionnaire

Do you have any formal or informal music training (voice or an instrument)?

- Yes
- No

Display This Question:

If Do you have any formal or informal music training (voice or an instrument)? Yes Is Selected

Which instrument (s)?

Display This Question:

If Do you have any formal or informal music training (voice or an instrument)? Yes Is Selected

Please indicate the type of training you have

- School/band
- Private lessons
- Church
- Friends/family
- Self-taught
- Other

Display This Question:

If Do you have any formal or informal music training (voice or an instrument)? Yes Is Selected

At what age did you begin your music training?

Display This Question:

If Do you have any formal or informal music training (voice or an instrument)? Yes Is Selected

What is the **total** number of music training years you have (formal or self-taught) on all instruments combined?

Display This Question:

If Do you have any formal or informal music training (voice or an instrument)? Yes Is Selected

How many years of training do you have on each instrument?

Display This Question:

If Do you have any formal or informal music training (voice or an instrument)? Yes Is Selected

How many years have you played music for? Please include a) the total number of training years and b) all years after training ended that you have continued to play (e.g., took piano for 5 years (overlapped with 2 years of guitar), have continued to play for an additional 10 = 15 years of playing).

Do you consider yourself a musician?

- ○ Yes
- ○ No

Do you have any formal or informal dance training?

- ○ Yes
- ○ No

Display This Question:
If Do you have any formal or informal dance training? Yes Is Selected

What style(s) of dance?

Display This Question:
If Do you have any formal or informal dance training? Yes Is Selected

Please indicate the type of training you have

- ☐ School
- ☐ Private/Group lessons
- ☐ Friends/Family
- ☐ Self-Taught
- ☐ Other

Display This Question:
If Do you have any formal or informal dance training? Yes Is Selected

At what age did you begin your training?

Display This Question:
If Do you have any formal or informal dance training? Yes Is Selected

How many **total** years of dance training do you have (formal or self-taught) in all styles combined?

Display This Question:
If Do you have any formal or informal dance training? Yes Is Selected

What is the maximum number of years you have trained in each style of dance?

Display This Question:
If Do you have any formal or informal dance training? Yes Is Selected

How many years have you danced for? Please include a) the total number of trining years and b) all years after training ended that you have continued to play (e.g., took ballet for 5 years (overlapped with 2 years of jazz), have continued to play for an additional 10 = 15 years of playing).

Do you consider yourself a dancer?

- Yes
- No

The next set of questions are about your performance during the experiment today.

Did you try to match your steps (synchronize) with the music while you walked today?

- Yes
- No

Display This Question:

If Did you try to match your steps (synchronize) with the music while you walked today? Yes Is Selected

Did it feel challenging for you to synchronize your steps with the music?

- Yes
- Somewhat
- No

Display This Question:

If Did it feel challenging for you to synchronize your steps with the music? No Is Not Selected

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 Is Selected

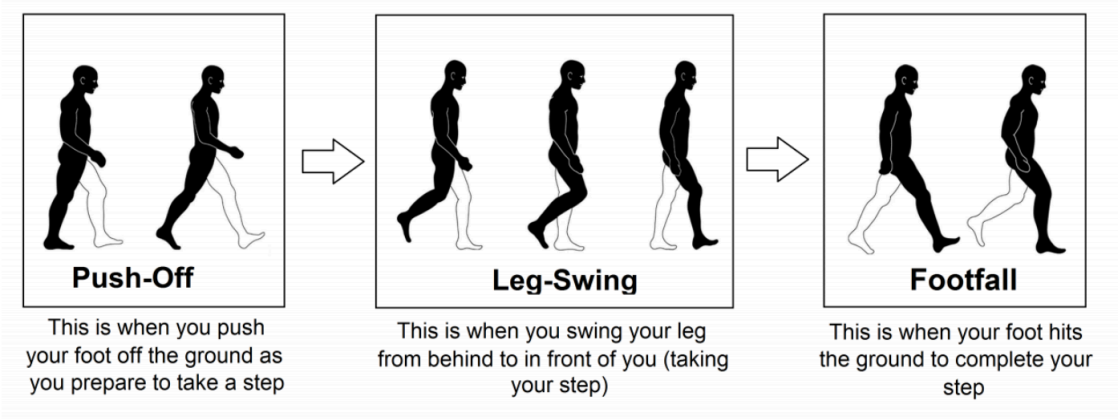
If you used any strategies to help you synchronize with the beat, please explain below.

Display This Question:

If Did you try to match your steps (synchronize) with the music while you walked today? Yes Is Selected

These images below represent leg movement during the walking cycle.

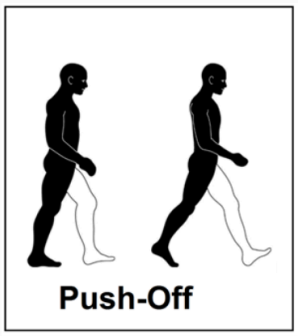
The titles correspond to the leg that is coloured in **black**.

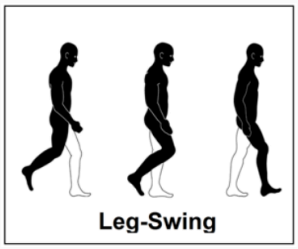


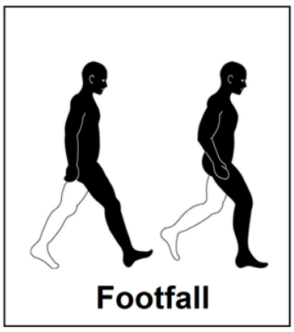
Display This Question:

If Did you try to match your steps (synchronize) with the music while you walked today? Yes Is Selected

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:







Did you feel it was challenging or uncomfortable to walk as instructed while trying to maintain big steps?

- Yes
- Somewhat
- No

Display This Question:

If Did you feel it was challenging or uncomfortable to walk as instructed while trying to maintain b... No Is Not Selected

You indicated that walking as instructed while trying to maintain big steps felt challenging or uncomfortable. Please elaborate:

Do you have any additional comments you would like to add?

Appendix E: Letter of Information

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: jgrahn@uwo.ca

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 jgrahn@uwo.ca. 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 (519) 661-3036, email: ethics@uwo.ca.

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 jgrahn@uwo.ca.

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 F: Debriefing Form

Western
The Brain and
Mind Institute

DEBFRIEFING FORM

The effect of the familiarity and enjoyment of music on gait responses.

Our lab is interested in determining what properties of music (i.e. groove, enjoyment, familiarity) lead to the most substantial movement improvements in Parkinson's. To do this, we test both healthy young adults and older adults with Parkinson's. The ultimate goal is to discover how music might be used to optimize outcomes from physical therapy in Parkinson's.

Evidence from the exercise science and clinical literature suggests that people are more willing to make effortful movements when moving to music [1]. We believe that this is due to the reward properties of music. Highly pleasurable music that elicit "chills" have been shown to evoke dopamine reward responses in the basal ganglia [2,3]. As dopamine affects the speed of movements, and that enjoyable music can affect the transmission of dopamine in the brain, listening to pleasurable music during movement may well improve the speed of movements by altering the effort/reward estimation of movement.

The purpose of this study is to examine the interaction between a person's familiarity of a piece of music with their enjoyment of it, as well as the effect that qualities such as the familiarity and enjoyment of a piece of music have on movement. In this study, songs of both high and low familiarity, and high and low enjoyment were played. You were asked to walk to the music. By participating in this study, you have provided us with valuable information to determine whether a person's familiarity with a piece of music has an effect on movement.

If you have questions about your rights as a research participant, you should contact the Director of the Office of Research Ethics at ethics@uwo.ca or 519-661-3036.

Research Investigators:

Dr. Li-Ann Leow (Post-doctoral Research Fellow)
Office: Brain and Mind Institute, NSC 234
E-mail: liann.leow@gmail.com
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Dr. Jessica Grahn (Principal Investigator)
Office: Department of Psychology, NSC 229
E-mail: jgrahn@uwo.ca
Number: 519-661-2111 ext. 84804

[1] Karageorghis, C. I. *et al.* Psychophysical and ergogenic effects of synchronous music during treadmill walking. *Journal of sport & exercise psychology* **31**, 18–36 (2009).

[2] Salimpoor, V. N., Benovoy, M., Larcher, K., Dagher, A. & Zatorre, R. J. Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature neuroscience* **14**, 257–62 (2011).

[3] Salimpoor, V. N., Benovoy, M., Longo, G., Cooperstock, J. R. & Zatorre, R. J. The rewarding aspects of music listening are related to degree of emotional arousal. *PloS one* **4**, e7487 (2009).

Appendix H: Follow-up T-tests for Step Length Instruction x Cue Type Interaction

Comparison	*M*	*SD*	*t*(32)	*p*
High Groove vs Low Groove	0.001	0.030	0.15	.885
High Groove vs Metronome	0.002	0.027	0.52	.604
Low Groove vs Metronome	0.002	0.026	0.37	.717

Note. Follow-up t-tests for differences in step length between step length instruction and no step length instruction conditions within each cue type reveal no significant differences.