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ARTICLE

Individuals With Parkinson's Disease Retain Spatiotemporal Gait Control With Music and Metronome Cues

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The purpose of this study was to determine the difference in spatiotemporal gait measures induced by stepping to the beat of a metronome and to music cues of various frequencies in individuals with Parkinson's disease. Twenty-one participants with Parkinson's disease were instructed to time their steps to a metronome and music cues (at 85%, 100%, and 115% of overground cadence). The authors calculated cadence, cadence accuracy, and step length during each cue condition and an uncued control condition. The music and metronome cues produced comparable results in cadence manipulation, with reduced cadence accuracy noted at slower intended frequencies. Nevertheless, the induced cadence elicited a concomitant alteration in step length. The music and metronome cues produced comparable changes to gait, but suggest that temporal control is more limited at slower frequencies, presumably by the challenge of increasing the step length.

Keywords: auditory, rhythm, step length, treadmill

The characteristic short, shuffling steps and tendency of individuals with Parkinson's disease (PD) to freeze during walking are often attributed to diminished automaticity (Morris, Martin, & Schenkman, 2010; Spaulding et al., 2013; Wu, Hallett, & Chan, 2015). Rhythmic auditory cueing is a well-established intervention intended to address these deficits in gait automaticity by adjusting cadence (Keus, Munneke, Nijkrake, Kwakkel, & Bloem, 2009). Previous studies have used either music or a metronome to provide the auditory cues (Ashoori, Eagleman, & Jankovic, 2015; Spaulding et al., 2013). Despite the potential advantages to both metronomes and music, prior attempts at quantifying their influence on spatiotemporal aspects of gait have been confounded by the production of different gait speeds during overground walking (Willems et al., 2006). In particular, altering gait speed via manipulation of cadence may not initiate the

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necessary changes in step length (Hoppe, Chawla, Browner, & Lewek, 2020). This is particularly important because individuals with PD exhibit substantial deficits in spatial measures (e.g., step length; Morris, Iansek, Matyas, & Summers, 1994), yet rhythmic auditory cueing directly addresses only the temporal features of gait. Thus, it remains unclear whether both of these auditory modalities can promote the intended spatiotemporal adjustments when decoupled from changes in gait speed.

A key benefit of a metronome is that the beat is discrete, enabling synchronization between the individual's steps and the beat (Ashoori et al., 2015; Leow, Parrott, & Grahn, 2014). Music, however, which may be more enjoyable than a metronome and is used commonly during exercise, may be less effective than the metronome due to the many layers of rhythms and beats that make musical sounds continuous rather than discrete (Rodger & Craig, 2016). Any difficulty in identifying the beat of a song may make it more challenging to adjust step timing appropriately (Leow et al., 2014). Nevertheless, several studies have examined the effect of music on gait mechanics and have found a generally favorable association between the use of music cues and increased stride length (Bella et al., 2017; Ford, Malone, Nyikos, Yelisetty, & Bickel, 2010; McIntosh, Brown, Rice, & Thaut, 1997; Spaulding et al., 2013). Potentially confounding these promising results, however, is the fact that these studies typically used a single musical track engineered to accentuate the rhythm to enhance detection. Translation to clinical environments is, therefore, limited, as preference for musical genre is not considered. Nevertheless, direct comparisons of gait mechanics while stepping to either music or metronome cues are rare in individuals with PD (Rodger & Craig, 2016; Rose, Delevoye-Turrell, Ott, Annett, & Lovatt, 2019). In studies involving healthy older adults, metronome cues elicit greater synchronization compared with music cues (Leow et al., 2014). However, both music and metronome cues effectively increased cadence, with only the musical cues leading to a concomitant increase in stride length and gait velocity of healthy older adults (Wittwer, Webster, & Hill, 2013).

Although the use of auditory cues has the potential to improve gait in individuals with PD, we are unaware of evidence to support the preferential use of music or metronomes for improving stride length in this population (Ashoori et al., 2015). The purpose of this study was therefore to determine the difference in spatiotemporal gait measures induced by stepping to the beat of a metronome and to music cues of various frequencies. We used treadmill gait to carefully assess potential changes in spatiotemporal gait parameters across various auditory cue conditions, without the confounding influence of altered gait speed (Lewek, 2011). Given the shortened step lengths observed in individuals with PD (Morris, Huxham, McGinley, Dodd, & Iansek, 2001; Morris et al., 1994), we were particularly concerned that individuals would exhibit difficulty in decreasing their cadence on the treadmill, because this would require a necessary increase in step length. Because gait speed was fixed by the treadmill, we hypothesized that attempts to decrease cadence (and increase step length) would be more challenging than attempts to increase cadence (and decrease step length). We further hypothesized that an inability to discern the tempo in the music accurately would reduce cadence accuracy compared with stepping with a metronome (Leow et al., 2014). As a result, we believed that changes in spatiotemporal measures would be particularly evident with metronome cues compared with music cues.

Methodology

Twenty-one individuals with PD participated in this study (13 males and eight females; age = 69.8 ± 9.8 years, Unified Parkinsons Disease Rating Scale [UPDRS] = 19.4 ± 13.7). The participants who met the following criteria were included: (a) medical diagnosis of PD (Postuma et al., 2015; Hoehn and Yahr Stages 1–3), (b) self-reported ability to walk >10 m overground without physical assistance, and (c) self-reported ability to walk on a treadmill for 14 min (with rest breaks, as needed). Potential participants were excluded due to the presence of uncontrolled cardiorespiratory or metabolic disease (i.e., uncontrolled hypertension, uncontrolled diabetes mellitus), other neurological or orthopedic disorders that may affect walking, or severe communication or comprehension impairments that would impede the ability to perform study procedures appropriately. With an average time since diagnosis of 8.8 ± 8.1 years, we recruited five individuals classified as Hoehn and Yahr Stage 1, nine individuals at Stage 2, and seven at Stage 3. All participants signed an informed consent form approved by the institutional review board of The University of North Carolina–Chapel Hill prior to participation. The project was listed on ClinicalTrials.gov (NCT03253965).

Each participant completed the Montreal Cognitive Assessment at the beginning of the testing session to characterize cognitive deficits (Montreal Cognitive Assessment = 27.0 ± 2.9). They then walked over a 6.1-m (20 ft) Zeno pressure mat (Prokinetics, Havertown, PA) to measure comfortable overground gait speed and cadence without the presence of auditory cues. We used the overground gait speed to guide treadmill speed selection and the overground cadence to determine the three target frequencies for auditory cues: 85%, 100%, and 115%. Except for three participants who walked slower on the treadmill than their typical overground speed, all other participants were able to match their typical overground speed during treadmill testing. The average overground gait speed was 1.15 ± 0.21 m/s, and the average treadmill speed used for testing was 1.10 ± 0.26 m/s ($p = .107$; $d = 0.37$).

The testing consisted of having all subjects walk during each of the following seven conditions on an instrumented treadmill: (a) no auditory cues (control), (b) timing their steps to a metronome set to 85% of overground cadence, (c) metronome at 100%, (d) metronome at 115%, (e) music at 85%, (f) music at 100%, and (g) music at 115%. We intentionally allowed each subject to select songs that matched the target frequencies from www.bpmdatabase.com. This was necessary to play each song at its correct tempo, rather than artificially slowing down or speeding up a single song. This decision enhances the ecological validity, although it potentially limits interpretation because we did not control for musical cue characteristics (e.g., high groove vs. low groove; Leow et al., 2014). Furthermore, any within-song change in tempo may increase the variability in stepping cadence. Conditions were block randomized for each participant, by type of auditory cue (music or metronome). The frequencies were randomized within each block. We always conducted the condition with no auditory stimuli (control) first. The participants were verbally instructed to "step to the beat" of the music or metronome (Mendonça, Oliveira, Fontes, & Santos, 2014), but no demonstration was provided. With each new condition, the participants took ~15 s to adjust to the tempo before we sampled 1 min of data. Rest breaks were provided between conditions, as needed. All participants had been on a treadmill at some point previously, but for safety purposes, each subject wore a harness that attached to the ceiling over the treadmill. The harness did not provide any body weight support and did not restrict limb motion. Handrails were available on the sides of the treadmill, though the participants were discouraged from using them.

Prior to walking on the treadmill (Bertec Corp., Columbus, OH), a single 14-mm retroreflective marker was taped to the posterior heel of each shoe. While walking, an eight-camera motion capture system (Vicon MX, Los Angeles, CA) sampled the 3D location of both markers at 120 Hz. Ground reaction forces were measured simultaneously, using the treadmill's force plates at 1200 Hz.

Data Processing and Outcome Measures

Marker trajectories and ground reaction forces were smoothed with a dual-pass 6-Hz and 20-Hz low-pass Butterworth filter, respectively. A custom LabVIEW program (National Instruments, Austin, TX) calculated the cadence and step length for each condition. Cadence was measured as the inverse of step time, determined from successive heel strikes when the vertical ground reaction force exceeded 20 N. We also computed mean cadence accuracy as the difference between the measured cadence and the target (intended) cadence. This measure represents how accurate the mean stepping cadence was to the target frequency from the music/metronome, although, admittedly, we can make no claims about how stable the stepping cadence was (i.e., the interbeat interval error) because we were unable to time stamp and synchronize the audio signal with the gait data. The step length was calculated by measuring the anterior–posterior distance between the right and left heel markers at each heel strike.

Data Analysis

The data analysis was performed using SPSS (version 25.0; IBM Corp., Chicago, IL). We first assessed mean cadence accuracy using a two-way repeated-measures analysis of variance (ANOVA), repeated for cue type (music/metronome) and frequency (85%, 100%, and 115% of overground cadence). In the presence of significant main or interaction effects, we performed one-way ANOVAs or paired sample t tests with a Bonferroni correction for post hoc analyses, as appropriate. The actual cadence was then compared with the intended cadence using paired samples t tests. We then used a one-way repeated-measures ANOVA to assess the specific effect of cueing on cadence compared with the uncued (control) condition. Finally, the step length changes were assessed using a two-way repeated-measures ANOVA. Again, we performed one-way ANOVAs or paired sample t tests with a Bonferroni correction for post hoc analysis, as appropriate. The effect sizes are documented as partial eta squared or Cohen's d. Prior to recruitment, we conducted a formal power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) to determine the proposed sample size. Our estimates were based on the current literature and expected findings. In particular, Wittwer et al. (2013) evaluated the effect of both music and a metronome on similar measures in unimpaired older adults. Although the population was different and they did not evaluate different frequencies, we used their results to estimate that we would need 18 participants to observe an effect size of 0.4 with an alpha of .05 and power of 0.80. Given the differences in test populations and the additional measures of frequency, we chose to be conservative and slightly overrecruit.

Results

We sought to determine how well participants were able to match their actual cadence with the intended cadence. We observed a Cue × Frequency interaction in mean cadence accuracy ($p = .007$, $\eta_p^2 = .221$, Figure 1). In particular, we noted greater cadence errors produced with music compared with the metronome at the 115% target only ($p = .003$; $d = 0.73$). The metronome and music cues produced comparable mean cadence accuracy at all other target frequencies ($p > .243$). Nevertheless, the participants were not able to achieve the intended cadence consistently. Specifically, we observed a higher actual cadence than what was intended for the 85% metronome ($p < .001$; $d = 1.07$) and 85% music ($p < .001$; $d = 1.29$) conditions. Additionally, we observed a lower cadence than intended in the 115% music condition ($p = .002$; $d = 0.75$).

Although the participants did not consistently achieve the target cadence, we still observed that the cadence produced was influenced by the presence of auditory cues ($p < .001$, $\eta_p^2 = .683$, Figure 2). Compared with walking without auditory cueing, the participants decreased their cadence while stepping to the 85% metronome ($p < .001$; $d = 1.21$) and 85% music ($p < .001$; $d = 0.96$) conditions, whereas the 115% metronome condition elicited an increase in cadence ($p = .004$; $d = 1.47$). Cues at 100% of overground cadence (metronome, $p = 1.00$; $d = 0.19$; music, $p = 1.00$; $d = 0.14$) and 115% music ($p = .069$; $d = 0.86$) did not alter cadence compared with walking without auditory cueing.

With regard to step length, a Cue × Frequency interaction was observed ($p = .008$, $\eta_p^2 = .215$, Figure 3). Although there were no differences in step length between the music and metronome at the 85% ($p = .141$; $d = 0.33$) and 100% ($p = .478$; $d = 0.16$) conditions, we observed that shorter step lengths were observed with the metronome compared with walking with music at the 115% condition ($p = .004$; $d = 0.71$). Furthermore, walking with the metronome elicited longer steps during the 85% condition (10% increase; $p < .001$; $d = 0.48$) and shorter steps during the 115% condition (11% decrease; $p < .001$; $d = 0.49$)

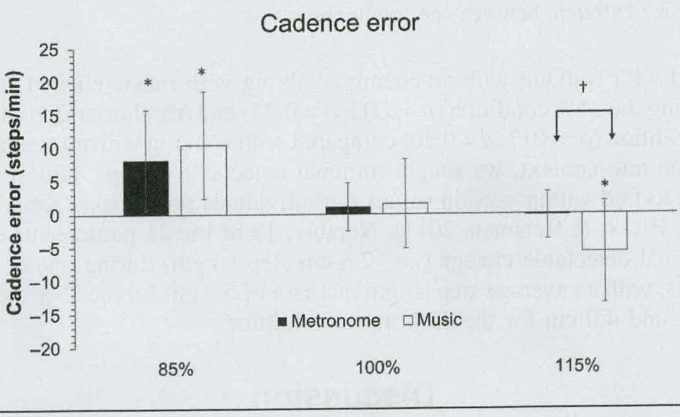

Figure 1 — Cadence error is depicted for the metronome (black) and music (white) conditions across frequencies. Error bars indicate *SD*s. *Different than intended cadence. †Different between cue conditions.

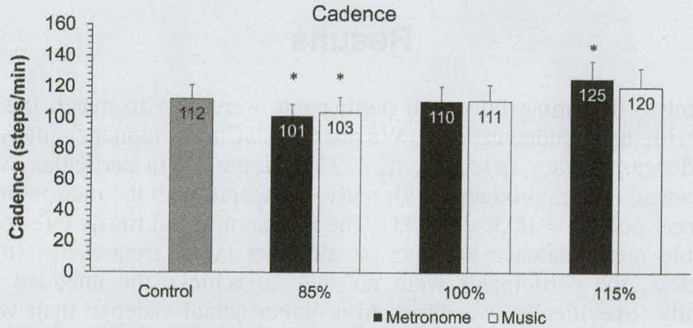

Figure 2 — Cadence during treadmill walking without auditory cues (control, gray bar) and with metronome (black) and music (white) cues. Error bars indicate *SD*s. *Different than control.

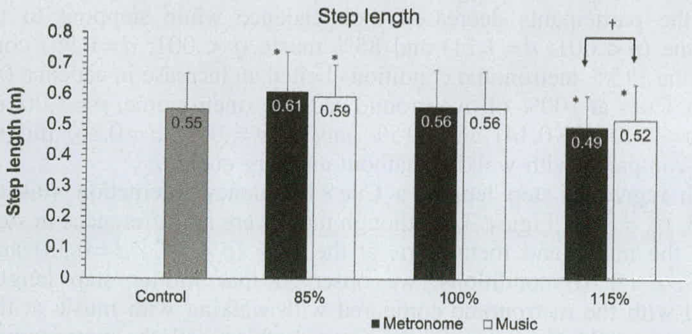

Figure 3 — Step lengths during treadmill walking without auditory cues (control, gray bar) and with metronome (black) and music (white) cues. Error bars indicate *SD*s. *Different than control. †Different between cue conditions.

compared with walking with no cueing. Walking with music elicited 7% longer steps during the 85% condition ($p = .003$; $d = 0.34$) and 6% shorter steps during the 115% condition ($p = .017$; $d = 0.30$) compared with walking with no cueing. To put the change into context, we sought minimal detectable change values, but were only able to find within-session values for individuals post stroke (Kesar, Binder-Macleod, Hicks, & Reisman, 2011). Notably, 19 of the 21 participants exceeded that minimal detectable change (i.e., 2.6-cm step length) during one of the 85% conditions, with an average step length increase of 5.7 cm for the 85% metronome condition and 4.0 cm for the 85% music condition.

Discussion

This study sought to determine how metronome and music cues of different frequencies would alter spatiotemporal gait parameters for individuals with PD.

We observed clear responses based on cueing frequency, but did not observe substantial differences between the metronome and music cues. Therefore, we can reject our hypothesis that metronome cues would elicit a greater response than music cues. We likewise reject our hypothesis that walking with slower frequency cues would not yield a large decrease in cadence. Although unable to achieve the slow target cadence, the slow frequency cues (i.e., 85% of typical overground cadence) produced significantly slower cadence, with the necessary concomitant increase in step length. These findings have implications for identifying parameters of auditory cues that are effective for facilitating longer step length in individuals with PD during treadmill ambulation.

For the purposes of applying these findings to therapy for individuals with PD, it is noteworthy that we observed increases in step length, despite the participants' inability to exactly match the target cadence. Surprisingly, the inability to step at the intended frequency occurred with both the music and metronome cues and suggests that the observed error may have had little to do with the cue itself. Instead, we attribute the cadence error, in part, to the participant's underlying timing impairment (Baltadjieva, Giladi, Gruendlinger, Peretz, & Hausdorff, 2006; Wu et al., 2015). Research involving unimpaired participants suggests that the ability to synchronize steps to rhythmic auditory cues is improved with faster music and music that the individual is familiar with (Leow et al., 2014; Leow, Rinchon, & Grahn, 2015). This synchronization of movement to a rhythmic auditory cue (i.e., entrainment) may be due to the function of important cortical and subcortical systems (Braunlich et al., 2019). By time locking steps to the auditory cue, individuals with PD can overcome deficits in internal timing regulation that impede gait. Control of gait is then enabled through external cues, rather than through internally generated timing cues. Despite the ability to adjust their gait to the rhythmic auditory cues, we observed small timing errors, which were larger at slower frequencies. In our cohort of participants with PD, we can speculate that this increased cadence error at slower frequencies was also due to the difficulty in concurrently having to take a longer step. Such deficits in step length regulation may be due to changes in the "gain" of motor function (Morris et al., 1994), deficits in motivation or reward circuitry in the basal ganglia, or a speed/accuracy trade-off that influences energy cost (Mazzoni, Hristova, & Krakauer, 2007).

Previously, musical cues have been associated with improvements in gait speed, cadence, and stride length (Bella et al., 2017; Ford et al., 2010; Thaut et al., 1996). It was suggested that the continuity of sound inherent in musical cues requires less cognitive demand than listening to cues that have a fixed beat, such as a metronome (Ashoori et al., 2015). Nevertheless, our participants subjectively reported greater difficulty identifying the tempo during music cues compared with the metronome cues. It is possible that some of the songs were considered "low-groove music" or that some of our participants exhibited deficits in beat perception, which we did not measure (Leow et al., 2014). Despite their perceived difficulty in identifying the musical beats, we failed to identify consistent differences in gait parameters when using the metronome or music cues. These data suggest that music may serve as a suitable surrogate to a metronome in clinical practice.

Importantly, prior studies often used musical tracks that were designed specifically to highlight the beat of the music to enable easy detection of the intended rhythm (McIntosh et al., 1997; Thaut et al., 1996). This is not always feasible or enjoyable to implement in the clinical or community setting. For this reason, we allowed the participants to select their own songs that coincided with the intended frequency. Familiar music creates greater entrainment than unfamiliar music, perhaps due to less cognitive demand (Leow et al., 2015). Furthermore, by allowing the participants to select their own music, we believe that we have a better representation of the effect of music use in a real-world setting. Because many people like to listen to music when they exercise or are active, this pragmatic approach is easily translatable to clinical settings.

Step lengths are notably shorter in individuals with PD (Morris, Iansek, Matyas, & Summers, 1996). Thus, therapists require approaches that have the capability of reliably and persistently increasing step length (Sherron, Stevenson, Browner, & Lewek, 2020). Indeed, we found that walking on a treadmill with a slower (i.e., 85%) cue frequency generates a longer step length at a given speed, whereas faster cues (115%) lead to a shorter step length (Hoppe et al., 2020). Our findings may appear in contrast with previous studies that demonstrated that *faster* cadence cues yield increased stride length (Picelli et al., 2010) or that stride length does not change with cue frequency (Howe, Lövgreen, Cody, Ashton, & Oldham, 2003; Lohnes & Earhart, 2011; Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004). Of note, however, is that these prior studies were performed overground, and the resulting ability to change gait speed could contribute to these discrepant findings. The results of our study extend prior work by demonstrating that, when we control speed with the treadmill, people with PD are able to take consistently longer steps for a given speed, using exposure to auditory cues at frequencies *slower* than their comfortable cadence.

Prior work on auditory cueing advocates for the use of higher frequencies to increase stride length and gait speed (Ashoori et al., 2015; Ford et al., 2010; Thaut et al., 1996). However, our data clearly suggest that, if individuals with PD practice walking on a treadmill, the use of higher frequency cues will result in *shorter* steps, which may exacerbate their deficits. This is particularly relevant because therapists commonly use treadmills to provide relevant external physical cues to enhance the automaticity of gait (Frazzitta, Maestri, Uccellini, Bertotti, & Abelli, 2009) and promote consistent stepping practice (Bello, Marquez, Camblor, & Fernandez-Del-Olmo, 2010; Frenkel-Toledo et al., 2005). Coupling treadmill walking with higher frequency cues, however, would be counterproductive. Instead, we propose that pairing slower auditory cues with treadmill walking would encourage longer steps (Sherron et al., 2020).

Limitations

There were several limitations to this study. First, some participants held on to the rails while completing the walking trials on the treadmill. Although handrail use may alter stride lengths for people with PD (Frenkel-Toledo et al., 2005), all individuals requiring handrails used them consistently across all conditions. This should presumably limit the effect on the within-subject comparisons that we performed. Second, each participant selected different songs from potentially different genres. It is also possible that we started these songs in a section where the beat may have been difficult to distinguish. Because of our pragmatic design, we were unable to control this limitation adequately without selecting a single song for use across subjects and conditions. Finally, we tested a different number of participants for each Hoehn and Yahr stage, resulting in a slightly larger number of participants classified as Stage 2 or 3. As a result, our results may not generalize as well to individuals classified as Stage 1.

In conclusion, our study demonstrated that participants with PD were unable to consistently meet slow cadence targets when walking on a treadmill at constant speed, although the slower auditory cues still elicited reductions in cadence (with concomitant longer step lengths). The music and metronome cues produced comparable changes to gait, suggesting that either form of cue may be effective at overcoming the shortened step lengths that are prevalent for individuals with PD.

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