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The Effects of Metronome Frequency and Walking Environment on Gait in People with

Parkinson's Disease

Abstract

Background: One of the most debilitating symptoms of Parkinson's disease (PD) is the loss of motor automaticity and resulting gait abnormalities. The use of a treadmill and rhythmic auditory cues may improve spatiotemporal gait parameters in this population. Both of these techniques are often used in the treatment of PD, however, there is little consensus on how the walking environment and frequency of metronome cues change gait.

Objective: The purpose of this study is to determine the effect of metronome cues on spatiotemporal gait parameters when walking overground compared to walking on a treadmill in people with Parkinson's Disease

Methods: Twenty-one people with PD walked overground and on a treadmill with metronome cues of 85%, 90%, 100%, and 115% of their baseline cadence. Gait speed, step length, and cadence were measured and compared for all trials.

Results: When walking overground, metronome cues of 85%, 90%, and 115% yielded changes in cadence and gait speed but not in step length. When walking on the treadmill, metronome cues of 85% and 115% yielded changes in step length while 85%, 90%, and 115% yielded changes in cadence. Gait speed did not change since the speed of the treadmill was controlled.

Conclusions: This data suggests that people with PD are able to manipulate their spatiotemporal gait parameters when provided the appropriate metronome cue and walking environment. The change in gait mechanics is dependent on the metronome cue and walking

environment used. Also, the ability to accurately match the metronome cue is not as important as providing the appropriate increased or decreased frequency.

<u>Introduction</u>

Parkinson's Disease (PD) is the 2nd most common neurodegenerative disorder, only behind Alzheimer's Disease.[1] The cardinal symptoms of PD include tremor, bradykinesia, rigidity, and postural instability.[2] One of the most common and debilitating symptoms in PD is gait abnormalities. Common gait disturbances include decreased step length, increased variability, freezing of gait, decreased gait speed, increased double support time, and increased cadence. [3–5] These gait abnormalities are associated with decreased motor automaticity which begins to deteriorate in the early stages of PD.[6] In an effort to improve gait mechanics and quality of life for individuals with PD, physical therapy is often prescribed.[7] Current research has focused on various techniques that can be used for gait training to minimize the deficits.

Given the automaticity and motor deficits in PD, it is not surprising that walking on a motorized treadmill induces different gait patterns by encouraging a more automatic gait due to the continuous belt movement compared to the self-generating gait pattern overground. In particular, both individuals with PD and healthy individuals decrease gait variability when walking on a treadmill compared to overground gait.[4] Unlike healthy adults, individuals with PD are known to take increased step lengths and decrease the cadence when walking on a treadmill compared to walking overground.[8] These changes are suspected to be due to a combination of the proprioceptive input from the belt displacement, visual cues of the distance from the front of the treadmill, and the constant velocity of the belt.[4,8]

The use of rhythmic auditory cues, such as a metronome, can successfully improve gait mechanics in people with PD. Since individuals with PD have impaired motor automaticity, attentional control must be used to perform skills that were once automatic, like gait.[6] External cues can successfully improve regulation of gait mechanics in people with PD.[6] The theory supporting the use of auditory cues for improving spatiotemporal gait characteristics is that the cerebellar-thalamocortical circuit that is responsible for synchronization remains intact with PD and so rhythmic cues can improve the internal motor activation that is impaired.[3] In practice, however, rhythmic auditory cuing has shown mixed results. Willems et al. examined the effects of metronome cues at various frequencies on overground gait mechanics in people with PD. They found that increased frequency resulted in increased cadence and gait velocity while decreased frequency of the metronome resulted in increased step lengths.[9] Another study found similar results and concluded that increasing gait velocity should be the primary goal of treatment so metronome cueing should only be used at frequencies that match or are faster than the individual's baseline cadence.[10] They suggest that using decreased metronome frequencies may result in increased falls risk because it increases both step length and variability.[10]

Previous research has demonstrated there is a therapeutic benefit from walking on a treadmill for individuals with PD. The use of a metronome to provide auditory cueing is a frequent strategy used in gait training and most studies have investigated these effects with over ground walking. One study concluded that a combination of auditory and visual cues on the treadmill was more effective than the same cues used overground.[11] They suggest that the treadmill provided an additional external cue that improved attention on gait and ultimately

improved gait speed and stride cycle after treatment.[11] To my knowledge, no study has

investigated the immediate effects of metronome at various frequencies on the treadmill.

Since a treadmill controls gait speed, changes in gait cadence can only be achieved by changing

step length. When walking overground, changes in cadence can be achieved by changes in step

length and/or gait speed. The purpose of this study is to determine the effect of metronome

cues on spatiotemporal gait parameters when walking overground compared to walking on a

treadmill in people with Parkinson's Disease. This information will be critical in order to

determine the optimal training environment to achieve specific gait training goals. I

hypothesize that due to the inability to change the gait velocity on the treadmill, individuals

with Parkinson's Disease will have more significant changes in gait parameters when walking on

the treadmill to metronome cueing than walking on the treadmill without cues or walking over

ground with and without cues.

Methodology

Participants

Participants were recruited from the community via referrals from the Department of

Neurology and from local Parkinson's disease support groups. All participants were diagnosed

with PD and had a Hoehn and Yahr (H&Y) Stage 1-3. Additional inclusion criteria included self-

reported ability to walk >10 m over ground and on a treadmill for at least 14 minutes with rest

breaks as needed. Exclusion criteria included H&Y Stage 4 and 5, uncontrolled

cardiorespiratory/metabolic disease, other neurological/orthopedic disorders that affect gait,

non-English speaking, and severe communication impairments that impeded understanding of

study purpose and procedures. Twenty-seven eligible participants were contacted and 21

agreed to participate. All participants were informed of the purpose and procedures associated with the study and signed an informed consent form approved by UNC-Chapel Hill.

Procedures

Participants were tested at the Human Movement Laboratory at the University of North Carolina-Chapel Hill. The Montreal Cognitive Assessment (MoCA) was administered for all participants to provide cognitive demographic data. A Unified Parkinson's Disease Rating Scale (UPDRS) was administered by a neurologist to determine the stage of PD. All participants were tested "on" medication. To determine baseline gait speed, each participant walked over a 16 ft Zeno Walkway (Protokinetics, Haverford, PA) with instruction to walk at their "comfortable speed." The Zeno software calculated baseline gait speed and cadence for every participant, which was used to determine the treadmill speed and metronome frequencies for the study.

Each participant performed 5 different trials of walking both overground and on a treadmill. The trials consisted of a baseline trial (no metronome) and 4 metronome trials of 85%, 90%, 100%, and 115% of the cadence calculated from the initial overground trial described above. The order of the metronome trials was randomized using a random number generator. The order of the treadmill and overground trials alternated between each testing subject. All participants wore a harness attached overhead, but no body weight support was provided and the harness did not restrict limb motion. Heart rate was monitored continuously using a pulse oximeter while walking on treadmill. The Google metronome was used and played through a speaker for all metronome trials.

Overground Testing

Each participant walked over the 16 ft Zeno Walkway 4 times for each testing condition. Instructions were given to "match each step to the beat of the metronome." No assistive devices were used during these trials. The first initial steps of each trial and the turns between each walk were completed off of the walkway and were not included in the data collection. Standing rest breaks were given as needed in between trials.

Treadmill Testing

Participants walked on a dual-belt instrumented treadmill (Bertec Corp, Worthington, OH) for all treadmill trials. The treadmill speed was set at the baseline gait speed calculated from the initial overground trial. For three subjects, the treadmill speed was reduced due to inability to reach the intended treadmill speed safely. Participants were discouraged from using handrails in order to promote more natural gait mechanics, however, 12 participants required handrails for balance. Each testing trial lasted 1 minute. Rest breaks were given as needed. Oxygen saturation and heart rate were monitored for safety. Instructions were given to "match each step to the beat of the metronome." A 1-minute baseline trial was performed first to allow for acclimatization to the treadmill before beginning metronome trials. Treadmill speed did not change throughout the duration of the treadmill trials. While participants walked on the treadmill, foot positions were tracked using markers on both heels and the Vicon Motion Capture system at 120 Hz. Ground reaction force data was also collected from the treadmill.

Data Management

For all overground trials, Prokinetic Software (pkmas) was used to collect data. This software removed partial steps and then automatically calculated step length, cadence, and gait speed from all remaining steps.   For all treadmill trials, the Vicon system calculated step

length by the anterior posterior distance between markers on each heel at heel strike. Cadence was calculated as the inverse of step time. Step time was calculated as every time heel strike occurred. A custom designed Labview Program was utilized to calculate outcome measures.

<u>Data Analysis</u>

SPSS version 24 was used for data analysis. Two-way repeated measures ANOVAs were used for step length and cadence. These were repeated for condition and environment. If significant main effects were found, paired sample T Tests were used as post hoc tests. Bonferroni correction was used for multiple comparisons. If significant interaction effects were found, one-way ANOVAs were used for each main effect. For cadence, one-way ANOVA was used to determine differences between environments and intended cadence at each target cadence. One-way ANOVA was also used for gait speed. A p-value of 0.05 was used for significance.

<u>Results</u>

<u>Participants</u>:

Twenty-one people with Parkinson's disease participated in this study (13 male, 8 female; 69.8 ± 9.8 years old). The average MoCA score was 27 (± 2.9). The average time since onset of initial symptoms was 10.5 years (± 7.7 years). Five of the participants were classified as H&Y Stage 1, nine were classified as H&Y Stage 2, and seven were classified as H&Y Stage 3. The average UPDRS score was 19.4 (± 13.7). The average motor axial subscore was 4.8 (± 3.5). Nine were classified as axial rigid and 12 as tremor predominant.

<u>Gait Speed</u>:

Gait speed was controlled on the treadmill for all trials. However, significant changes in gait speed were observed across conditions when walking overground ($p < 0.001$, $\eta^2_p = 0.762$). Gait speed significantly decreased for the 85% metronome condition ($p = 0.001$) and significantly increased for the 115% metronome condition ($p < 0.001$) compared to the baseline condition. There was a tendency to decrease gait speed for the 90% metronome condition ($p = 0.074$). No significant change in gait speed was observed for the 100% metronome condition (Figure 1).

Figure 1:

Gait Speed
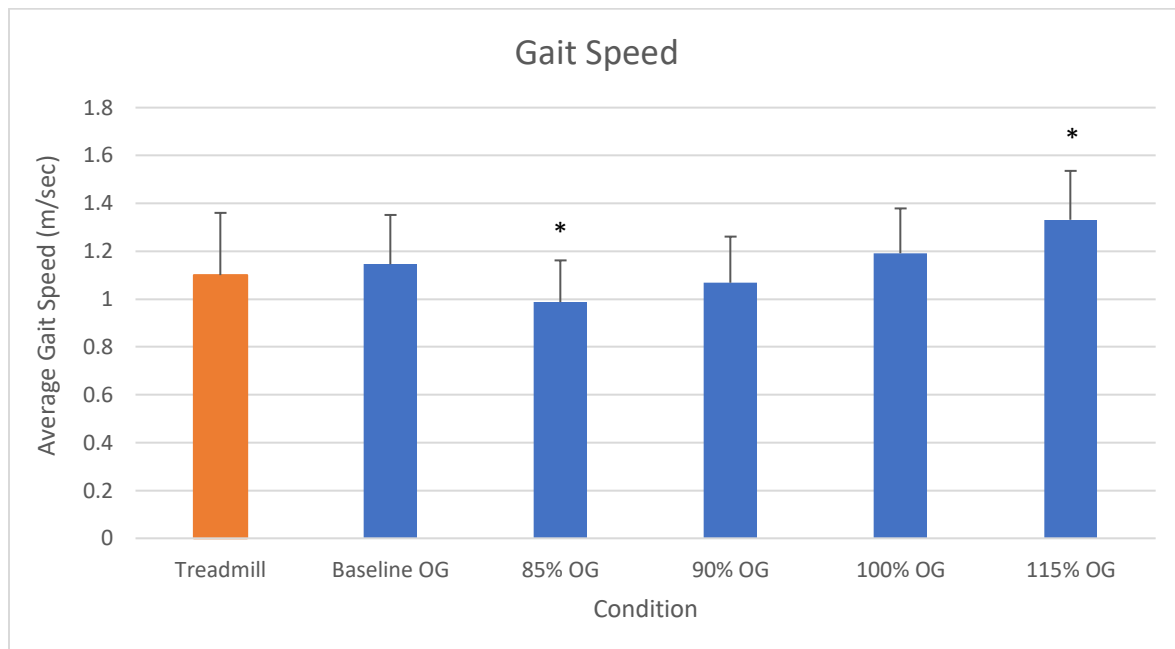
Step Length:

We observed a significant main effect for walking environment ($p = 0.003$, $\eta^2_p = 0.362$) with longer steps observed overground compared to on the treadmill. A significant interaction effect was observed between walking environment and metronome frequency ($p < 0.001$, $\eta^2_p = 0.48$). We therefore compared the effect of metronome frequency on step length on the treadmill and overground, separately. Here, we observed a significant effect of metronome

frequency on the treadmill only (p<0.001, η^2_p=0.656), but not during overground walking (p=0.172, η^2_p=0.083). Post hoc testing of treadmill walking revealed that use of lower frequencies of metronome cues yielded significantly larger step lengths, with higher frequencies inducing smaller step lengths (Figure 2).

Figure 2:
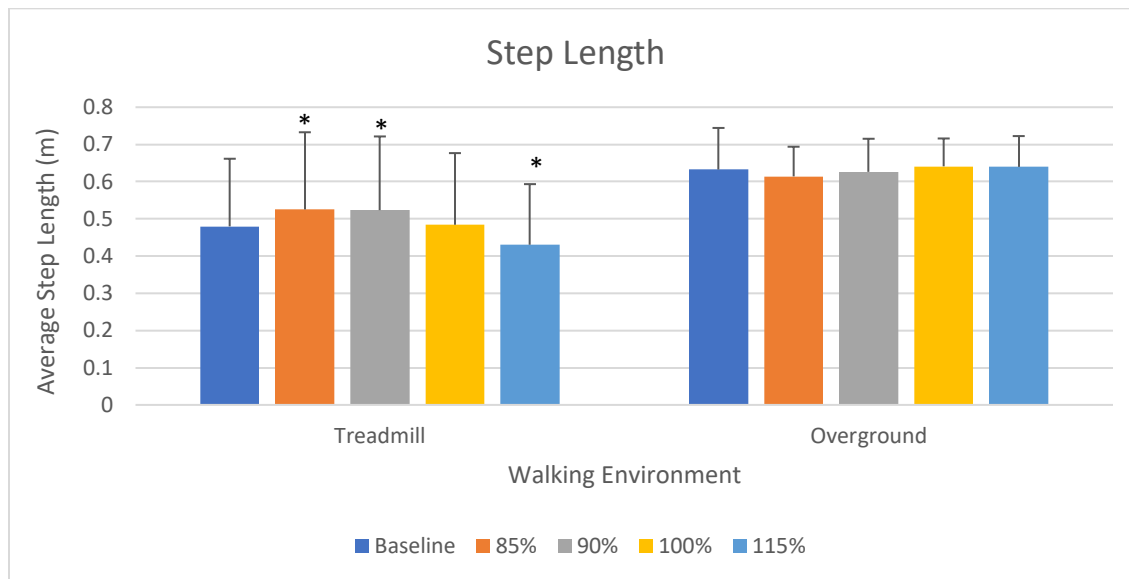
Cadence:

We observed a significant interaction for cadence between walking environment and metronome frequency (p=0.037, η^2_p=0.199). The interaction effect appeared to be due to the difference in cadence at 85% between treadmill and overground walking (p=0.006), whereas all other frequencies were not significantly different (all p>0.256). Given the significant interaction effect, we further assessed the effect of metronome frequencies for the treadmill (p<0.001, η^2_p=0.782) and overground (p<.001, η^2_p=0.903) environments separately. We were careful to include the intended frequency in our analyses as we sought to determine how well participants could reproduce targeted frequencies (Figure 3). We observed that for both the

85% metronome condition ($p<0.001$, $\eta^2_p=0.426$) and the 90% metronome condition ($p=0.001$, $\eta^2_p=0.302$) that cadence was significantly faster on both the treadmill and overground compared to intended cadence. Additionally, walking on the treadmill had significantly higher cadence at 85% compared to overground ($p<0.001$). There were no significant differences for the 100% or 115% conditions.

Figure 3:
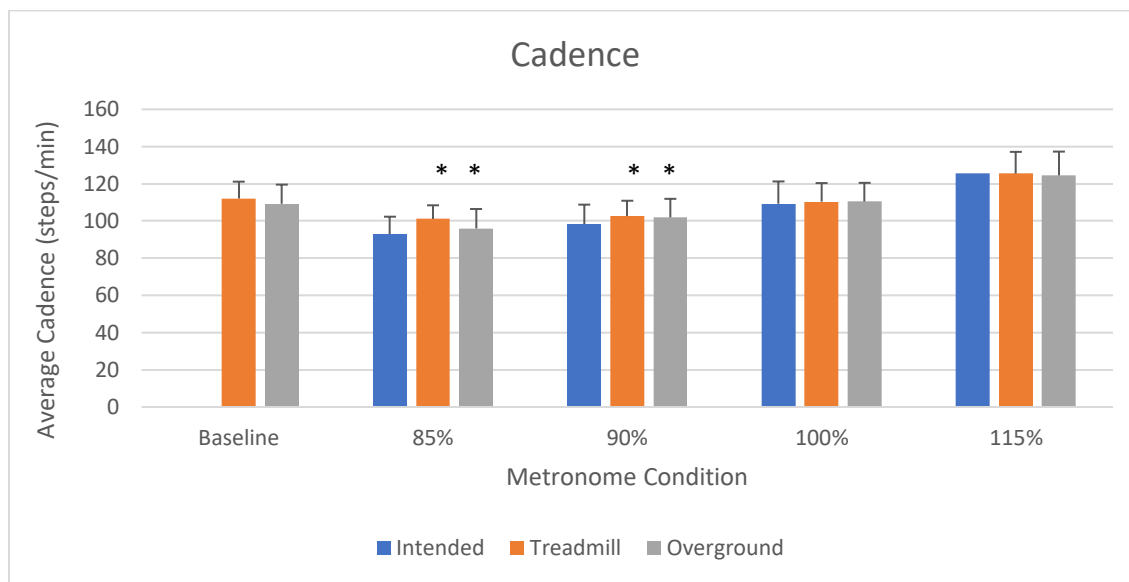
Discussion:

My hypothesis that metronome cues on the treadmill would yield more significant changes in gait mechanics in people with PD compared to overground with and without metronome cues was partially supported. The optimal cueing and walking environment depends on the specific change in gait parameters desired. Specifically, for gait speed, metronome cueing at 85% and 115% overground yielded greater changes than all other trials. For step length, metronome cueing at 85%, 90%, and 115% on the treadmill yielded greater

changes compared to all trials overground. In regards to cadence, participants had difficulty reaching the intended cadence for 85% and 90% metronome cues, however, walking overground yielded a greater decrease in cadence for those conditions compared to walking on the treadmill.

This study demonstrated that people with PD have the ability to change their gait in response to metronome cues both overground and on the treadmill. The mechanism underlying rhythmic cuing induced gait changes may lie in the ability to provide external regulation of rhythmic timing. Importantly, functional magnetic resonance imaging (fMRI) studies have demonstrated diminished activation in many locomotor areas of the brain that control timing of gait in people with PD.[12] This altered activation impairs the ability to independently modify gait mechanics through internal regulation[3]. By providing external cues, like the metronome and treadmill, less demand is placed on internal regulation of gait. Since the motor circuits for synchronization remain intact, the use of treadmill and rhythmic auditory cues should improve gait mechanics in ways the person would not be able to change and maintain independently.[4,8–10] Our results supported this theory demonstrated by the changes observed in gait speed, step length, and step cadence in response to the metronome cues and walking environment.

This study also demonstrated that treatment must be specific to the desired goal. Treatment plans must be designed to promote the ultimate goal of treatment based on available evidence, clinician knowledge, and experience. It is critical that treatment matches the desired goal. When developing a treatment strategy, a hypothesis should be formulated that the chosen treatment plan will achieve the desired outcome.[13] Common gait

abnormalities in people with PD include decreased gait speed, decreased step length, and increased cadence.[3–5] Therefore, treatment goals often include increasing gait speed, increasing step length, and decreasing cadence. Based on the results from this study, to increase gait speed, walking overground with the 115% metronome cue is the only treatment option that produced increased gait speed. If the goal is to increase step length, walking on a treadmill with 85% or 90% metronome cues is the only treatment option that promoted larger step length. To decrease cadence, the 85% and 90% metronome cues must be used either overground or on the treadmill, however, overground resulted in a greater reduction of cadence compared to the treadmill at these frequencies.

This study also demonstrated that the frequency of the cue provided is more important than the person's ability to successfully match the cue. Participants in this study were only able to accurately match their step with the 100% and 115% metronome cues both overground and on the treadmill. Although they were unable to match the 85% and 90% cues, those conditions still produced significant changes in spatiotemporal gait mechanics. Thus, even when the cue is not accurately matched, the desired gait changes can still be observed.

There were several limitations to this study. First, some participants used the handrails on the treadmill and some did not. In healthy adults, the use of handrails when walking on a treadmill significantly decreases step length and width variability but not step time variability.[14] Not surprisingly, step variability increases when walking without handrails in people with PD.[4] This is likely because handrails provide support for improved balance and mobility.[4] In healthy adults, there is no significant difference in step length found between holding or not holding handrails on treadmill.[15] Most untrained people, especially those with PD, require handrails to

safely perform treadmill walking and many studies do not report whether handrails were used.[4] Although gait variability was not one of the outcomes assessed in this study, there is potential for differences in gait mechanics depending on use of handrails. Since a harness was worn on the treadmill but not overground, there is potential that fear of falling may have been removed for treadmill trials but not for overground trials. There was also potential for fatigue-related changes in gait since no rest breaks were given unless the patient requested one or heart rate or gait quality indicated the need for one. Lower extremity fatigue in PD impacts gait parameters including step length and gait speed.[16] Finally, there were more people with stage 2 and 3 PD than stage 1, so these results may be more heavily influenced by more advanced PD.

In conclusion, I observed a significant relationship between frequency of metronome cues and walking environment for gait mechanics in people with PD. The desired gait change (i.e. gait speed, step length, or cadence) directly influences the type of cue and environment used in order to achieve that goal. People with PD are able to successfully change their gait speed, step length, and cadence in response to these conditions; however, further exploration is needed to determine if these results can used as a gait training technique that carries over to long-term gait changes.

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