Novel Challenges to Gait in Parkinson’s Disease: The Effect of Concurrent Music in Single- and Dual-Task Contexts

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Objective: To investigate the effect of concurrent music on parkinsonian gait in single- and dual-task contexts.

Design: A university balance research laboratory.

Participants: People with idiopathic Parkinson’s disease (PD) (n=10) (67±7y) and healthy age-matched (65±6y) control subjects (n=10).

Intervention: Subjects walked at a self-selected pace along an unobstructed walkway in 4 differing test conditions. Test conditions were differentiated by the presence of music accompaniment (no music/music) and the presence of a secondary cognitive task (single/dual). Single- and dual-task conditions were randomized; trials were blocked by the presence of music and counterbalanced between subjects. Music was self-selected by subjects. The cognitive task consisted of serial subtractions (3’s). Subjects were not instructed to attend to the music nor were they provided with instructions regarding task prioritization.

Main Outcome Measures: Mean gait velocity, stride length, and the percentage of the gait cycle spent in double-limb support.

Results: Gait among the PD patients was adversely affected by concurrent music. In contrast, gait performance in the control subjects showed no significant difference between no music/music and the presence of a secondary cognitive task (single/dual). Single- and dual-task conditions were randomized; trials were blocked by the presence of music and counterbalanced between subjects. Music was self-selected by subjects. The cognitive task consisted of serial subtractions (3’s). Subjects were not instructed to attend to the music nor were they provided with instructions regarding task prioritization.

Conclusions: Gait impairments associated with PD are exacerbated in the presence of concurrent music, an effect that is further exaggerated by the addition of a cognitive task. These results have implications for patient safety in multitasking situations.

Key Words: Gait; Music; Parkinson disease; Rehabilitation. © 2009 by the American Congress of Rehabilitation Medicine

PARKINSONIAN GAIT is typically characterized by reduced gait velocity, decreased stride length, and an increased cadence.1 Despite the overall effectiveness of dopaminergic drugs in the symptomatic treatment of PD, a number of gait deficits often remain resistant,2 over time becoming some of the most incapacitating symptoms of this disease. The persistence of gait impairments has necessitated the exploration of rehabilitation therapies that potentially complement pharmacologic therapies and assist in the management of gait difficulties. One therapy, established to be effective in facilitating parkinsonian gait, is the provision of external spatial or temporal stimuli that serve to cue the gait cycle. Immediate beneficial effects, with improvements in spatiotemporal parameters of parkinsonian gait, have been shown in studies using a variety of cue modalities, such as visual,3-5 auditory,6-9 and attentional cues.3,10,11 Despite the well-established benefits of these cue modalities in facilitating parkinsonian gait across both single- and dual-task conditions,3,6-10,12-16 there are a number of limitations presented by commonly prescribed cueing strategies. For example, visual cueing tools can lack practicality,15 whereas auditory cues can tend toward repetitiveness and a potential for habituation.16 These disadvantages carry the potential to challenge patient vigilance and subsequently compromise compliance, potentially leading to the discontinuation of use. One practical solution to overcome these limitations is to explore solutions that are meaningful to the patient and therefore may serve to encourage sustainability of these therapies.

Auditory cueing has been identified as the therapy of choice by PD patients in the home environment,17 an important consideration when developing sustainable, relevant gait therapies. Within the domain of auditory cueing, the integration of music has been identified as an attractive alternative to a simple metronome tone. The use of music to stimulate movement among PD patients is not a new phenomenon, and the viability of incorporating music in gait management strategies has been confirmed by others.8,9,12,18 McIntosh,8 Thaut,9 and colleagues used original musical pieces with a rhythmic accentuated beat to significantly improve gait among PD patients. Yet, despite this encouraging evidence for the use of music in pathologic gait rehabilitation, it is difficult to elucidate whether the observed improvements in spatiotemporal parameters of gait provide further evidence for temporal cueing mediated by the imposed accentuated beat or whether they represent a response to the music selection. Although the beneficial outcome of this intervention cannot be denied, it would be valuable to determine
whether any effect can be imparted with contemporary commercial music that, although intrinsically rhythmic, has not had the tempo accentuated or manipulated. Indeed, other qualities beyond the tempo of a music selection may influence motor output (eg, familiarity and meaningfulness are known to significantly affect arousal levels),\textsuperscript{18} which could conceivably result in modulated gait performance. This possibility would provide foundation to develop individualized gait management strategies that, although readily accessible, may more closely imitate real-world situations in which walking with music has become a daily phenomenon.

The current study sought to determine the effect of concurrent music on gait performance among patients with PD in single- and dual-task contexts. To strengthen generalizability, subjects were asked to select their own music accompaniment founded on the criteria of enjoyability and familiarity. Based on the phenomenon that music can stimulate movement in the healthy\textsuperscript{19,20} and parkinsonian\textsuperscript{8,9} populations, we hypothesized that spatiotemporal gait parameters would be improved across both test conditions for all subjects in the presence of concurrent music.

METHODS

Subjects

Ten patients with idiopathic PD (mean age, 66.6±6.5y; 5 women; clinical characteristics in table 1) and 10 controls (mean age, 65.4±6.3y; 8 women) participated in this study. The Human Research Ethics Committee of the University of Lethbridge granted ethical approval of the study. All subjects were informed of the nature of the study and gave their informed written consent before the commencement of testing. PD patients were recruited through local neurology clinics and PD support groups. Inclusion criteria were confirmed diagnosis of idiopathic PD (by a consultant neurologist), mild to moderate stable antiparkinsonian medication regimen (for at least 1 month before testing), independently mobile without use of a walking aid, and adequate hearing. Patients were excluded if their disease duration was less than 1 year, they scored less than 26 on the Mini-Mental Status Examination,\textsuperscript{22} they suffered from any neurologic condition or comorbidity likely to affect gait, and/or if they were already walking to music. Medical history and medication usage (see table 1) were ascertained before testing through a comprehensive interview. The impairment status of PD patients was assessed by using the motor subsection of the Unified Parkinson’s Disease Rating Scale.\textsuperscript{23}

Protocol

The testing protocol for this study represented test conditions to assess the effect of concurrent music on gait in single- and dual-task conditions and the effect of music on gait performance in a complex walking task (obstacle negotiation). Obstacle negotiation trials will be addressed in a separate paper because of the differences in motor patterns used between steady-state and obstructed walking.

Subjects were asked to walk the length of an unobstructed 10-m walkway at a self-selected pace. Test conditions were differentiated by the presence of music accompaniment (no music/music) and the requirement to perform a concurrent secondary cognitive task (no task/cognitive task) as follows: condition 1: no music, no task; condition 2: music, no task; condition 3: no music, cognitive task; and condition 4: music, cognitive task.

Music was selected based on the subjects indicated genre, artist, or track preferences during a prior telephone interview. The cognitive task consisted of serially subtracting 3’s (aloud) from a random 3-digit number. A new starting number was provided for each trial in the dual-task conditions immediately before the commencement of the trial. Subjects were not provided with specific instructions regarding task prioritization nor were they instructed to direct attention toward the music.

Subjects performed a total of 6 trials in each of the conditions (N=24 trials). Order and practice effects were controlled for by randomizing the order of task (no task, cognitive task) presentation. Trials were blocked by the presence of music (no music trials/music trials); the blocks were counterbalanced between subjects. One practice trial was performed before the start of the testing session. All subjects with PD were tested on medication (minimum of 1h postmedication). Patients were shadowed by a trained researcher to ensure safety.

Apparatus

Three-dimensional kinematic data were collected at 120Hz by using a 6-camera motion analysis system (Peak Performance Technologies and Vicon Motus 9.0 software).\textsuperscript{24} Retroreflective markers were placed on the sternal notch and bilaterally on the acromion process, lateral humeral epicondyle, ulnar styloid process, greater trochanter, lateral femoral condyle, lateral malleolus, the dorsal aspect of the foot between the first and second metatarsal, and the calcaneus. A microphone headset and computer with an integrated audio card were used to capture the participant’s verbalizations during the dual-task trials (8000Hz, Microsoft Sound Recorder, Version 5.1).\textsuperscript{25} An iPod Nano\textsuperscript{25} with headphones was attached to the subject’s waistband to provide the subject with music at a self-selected volume during trials in the music condition.

Data Processing

Custom-written algorithms were created in MATLAB (Version R2007a)\textsuperscript{9} to process raw marker data and calculate spatiotemporal parameters of gait. Raw marker data were filtered at 10Hz (low-pass fourth-order Butterworth filter). Whole-body COM in the AP dimension was calculated with a 7-segment model by using predetermined anthropometric values.\textsuperscript{24} The finite differences method was used to calculate AP COM velocity.

The event of right heel contact was used to crop kinematic data into gait cycles. Spatiotemporal parameters of gait con-

### Table 1: Clinical Characteristics of Parkinson’s Disease Patients

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (y)</th>
<th>Disease Duration (y)</th>
<th>Hoehn and Yahr</th>
<th>UPDRS (III)</th>
<th>Medications</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD 1</td>
<td>71</td>
<td>3</td>
<td>2.0</td>
<td>24</td>
<td>Levodopa</td>
</tr>
<tr>
<td>PD 2</td>
<td>76</td>
<td>4</td>
<td>3.0</td>
<td>26</td>
<td>Levodopa</td>
</tr>
<tr>
<td>PD 3</td>
<td>73</td>
<td>9</td>
<td>2.0</td>
<td>30</td>
<td>Levodopa</td>
</tr>
<tr>
<td>PD 4</td>
<td>62</td>
<td>1</td>
<td>2.0</td>
<td>30</td>
<td>Pramipexole</td>
</tr>
<tr>
<td>PD 5</td>
<td>74</td>
<td>8</td>
<td>2.5</td>
<td>26</td>
<td>Levodopa</td>
</tr>
<tr>
<td>PD 6</td>
<td>65</td>
<td>2</td>
<td>2.0</td>
<td>30</td>
<td>Levodopa</td>
</tr>
<tr>
<td>PD 7</td>
<td>58</td>
<td>12</td>
<td>2.5</td>
<td>26</td>
<td>Levodopa</td>
</tr>
<tr>
<td>PD 8</td>
<td>61</td>
<td>13</td>
<td>2.0</td>
<td>30</td>
<td>Levodopa,</td>
</tr>
<tr>
<td>PD 9</td>
<td>66</td>
<td>10</td>
<td>2.5</td>
<td>30</td>
<td>Levodopa,</td>
</tr>
<tr>
<td>PD 10</td>
<td>60</td>
<td>2</td>
<td>2.5</td>
<td>30</td>
<td>Levodopa</td>
</tr>
</tbody>
</table>

NOTE. Hoehn and Yahr and UPDRS (III) scores were measured in the on medication condition. Abbreviation: UPDRS, Unified Parkinson’s Disease Rating Scale.
provided in tables 2 and 3, respectively. The mean tempo and rhythmic content of the playlists selected for the music condition consisted of (1) AP COM velocity (gait velocity), (2) stride length, and (3) percentage of the gait cycle duration spent in DLS as per previous studies in this area.7,25 Mean values were calculated across gait cycles and within each condition for all measures. Based on foot-fall position a minimum of 2 gait cycles per trial were available for analysis.

Cognitive task data were scored manually to determine the total number of verbalizations per trial as well as the number of incorrect responses and the relative performance score (percent errors) for each trial. Mean values were calculated across each condition for each measure.

The tempo of each musical track was independently determined by 2 raters by using a DJ sequencer software (Jackson 1.34).26,27 An intraclass correlation was calculated to determine interrater reliability. The intraclass correlation of 0.860 (95% confidence interval, .751–.924) indicated strong agreement between raters. Musical tracks were determined to be lyrical or instrumental based on the presence or absence of vocals within the piece.

Statistical Analysis

Data were analyzed by using SPSS for Windows (Version 16.0).4 Demographic data were summarized descriptively and compared between groups by using independent t tests. The properties of music selections (mean tempi and lyrical content) were quantified; between-group differences were compared by using independent t tests. Cognitive task data were entered into separate, mixed 2-factor (group [controls/PD] × music [no music trials/music]) repeated-measure ANOVA. Gait measures were entered into separate mixed 3-factor (group [controls/PD] × music [no music trials/music] × task [single/dual]) repeated-measure ANOVA to determine the effect of task, music, and group on the spatiotemporal measures of gait specified in this study. ES was reported with partial Eta squared values. Statistical significance was set at .05.

RESULTS

Descriptive statistics and summary statistical findings are provided in tables 2 and 3, respectively. The mean tempo and lyrical content of the playlists selected for the music condition did not differ significantly between the control and PD groups (t18=1.370, P>.05, and t18=1.273, P>.05, respectively).

PD patients tended to articulate more numbers (fig 1A) and produce a higher percentage of errors (fig 1B) than the control group during the secondary cognitive task across both music conditions; these group differences did not reach significance (P>.05). In addition, the PD group produced more errors during the concurrent music trials, whereas the control group tended toward fewer errors in the music condition; this differential effect was not significant (F1,18=1.014, P=.327, ES=.053) (see fig 1B).

PD patients consistently walked significantly slower (F1,18=5.3.59, P=.033, ES=.229) and tended toward shorter strides (F1,18=3.632, P=.073, ES=.168) and a longer DLS phase (F1,18=3.784, P=.068, ES=.174) across all conditions when compared with the control group (fig 2A–C).

Listening to music while walking had a differential effect on gait performance among PD patients when compared with control subjects, as confirmed by a significant interaction between music and group for DLS (F1,18=10.528, P=.004, ES=.369, PD=9.7% increase, controls=2.8% decrease) and interactions approaching significance for gait velocity (F1,18=3.503, P=.078, ES=.163, PD=2.2% decrease, controls=1% increase) and stride length (F1,18=3.342, P=.084, ES=.157, PD=1.9% decrease, controls=1% increase).

When challenged by a concurrent cognitive task, both the Parkinson’s subjects and control subjects adjusted their gait patterns to walk slower (F1,18=16.443, P=.001, ES=.477, PD=21% change, controls=8% change), with shorter strides (F1,18=29.811, P<.001, ES=.624, PD=7% change, controls=5% change), and a longer DLS duration (F1,18=4.251, P=.054, ES=.191, PD=10% change, controls=6% change). However, the task by group interactions failed to reach significance (P>.05).

As confirmed by a significant 3-way (task × music × group) interaction, the added requirement of concurrent music in the dual-task context differentially influenced walking velocity (F1,18=4.553, P=.045, ES=.205) between PD patients and control subjects. Specifically, PD patients showed a further 4% decrease in walking velocity, beyond the 20% decrease imposed by the dual task, when required to perform the dual task in the concurrent music condition. Conversely, the noted detrimental dual-task effect was less pronounced among the control group in the concurrent music condition with healthy control subjects showing a 3% increase in velocity when compared with the baseline dual-task condition (no music) (see fig 2A). The same pattern of differential effect was noted for stride length (see fig 2B) and DLS duration (see fig 2C); however, these interactions did not reach significance (P>.05). Indeed, of noteworthy mention is the striking effect of concurrent music in the dual-task context among PD patients when compared with control subjects for the measure of DLS. As shown

### Table 2: Summary of Descriptive Statistics for Gait Parameter in the Control and Parkinson’s Disease Groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CTRL NM</th>
<th>CTRL M</th>
<th>PD NM</th>
<th>PD M</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM velocity (m/s)</td>
<td>1.41±.11</td>
<td>1.41±.10</td>
<td>1.28±.13</td>
<td>1.31±.13</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>1.41±.05</td>
<td>1.43±.06</td>
<td>1.34±.07</td>
<td>1.36±.08</td>
</tr>
<tr>
<td>Double-limb support (%)</td>
<td>23.7±1.26</td>
<td>23.8±.83</td>
<td>25.9±.78</td>
<td>24.5±.98</td>
</tr>
</tbody>
</table>

**NOTE.** Values are mean ± SD. Abbreviations: CTRL, healthy age-matched control subject; NM, no music trials; M, music trials.

### Table 3: Summary of Statistical Findings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>G M T</th>
<th>M×G</th>
<th>T×G</th>
<th>G×T</th>
<th>M×T</th>
<th>T×M×G</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM velocity (m/s)</td>
<td>* NS</td>
<td>.078 NS NS NS *</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>.073 NS .084 NS NS .074</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double limb support (%)</td>
<td>.069 NS * NS NS NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: G, group; M, music; T, task; NS, nonsignificant difference. *P<.05; †P<.01; ‡P<.001.
in figure 2C, the gait pattern of the PD patients included a further prolonged DLS phase (8%) for the dual-task trials that were performed with concurrent music compared with the no music dual-task trials. Again, the opposite was observed in the control group who decreased the duration of the DLS phase by 3% when performing the dual task with concurrent music.

DISCUSSION

The findings of this study showed that the gait patterns of PD patients were altered in concurrent music trials, interestingly in a manner similar to the dual-task effect imposed by performing a secondary cognitive task. Consequently, we were not surprised by the observation that the dual-task effect was exacerbated for PD patients but not control subjects in the concurrent music trials. The similarity observed between the gait interference exacted by concurrent music to the phenomenon of dual-task decrement implies the possibility that concurrent music imposes added cognitive demands that may interfere with the attentional control of gait in the PD population. Indeed, previous research investigating the influence of music on cognitive and motor performance in nonneurologic populations similarly suggests that music adds to the cognitive load, acting as a distraction from the primary task. This theory points caution for patients who may enjoy listening to music while walking or exercising.

Effect of Concurrent Music on Gait in Single and Dual Task Contexts

Contrary to our hypothesis, our results revealed a differential effect of music on gait performance between control and PD subjects. More specifically, control subjects did not show an effect of music in the walking-only condition. Marginal increases in gait velocity, stride length, and a decrease in the duration spent in DLS were observed in the dual-task context with concurrent music. Moreover, the alterations observed in the spatiotemporal measures of gait were not at the expense of cognitive performance. Conversely, PD patients showed a significantly longer proportion of the gait cycle spent in DLS while listening to music in the walking only condition. When the patients were required to also perform the arithmetic task, the increase in DLS duration was further exacerbated, and patients showed slower gait speed and shorter strides.

One possible explanation of the gait deficits observed for the PD patients in the concurrent music trials is that the presence of music imposed an added cognitive demand for the patients. Although the subjects in this study were not instructed to attend to the music, the music provided was patient selected. There-
fore, it is probable that the subject may have actively focused attention to the music. In this scenario, listening to the music may have effectively acted as an additional task, thereby creating a dual-task situation that is especially difficult for PD patients to manage.30 People with PD are required to assign greater attentional resources to the control of gait when compared with the nonneurologic population, in part because of a disruption in the automaticity of movement control.31,32 Although conscious motor control enables successful movement execution, it may diminish residual attentional resources. Therefore, if listening to concurrent music is imposing a cognitive load, residual attentional resources may be further reduced, leading to a detriment in 1 or more tasks.

Alternatively, the group-dependent differences observed in gait performance may reflect differing effects of affective arousal mediated by the self-selection of the musical pieces. The arousal potential of music is considered to be regulated by factors that are intrinsic to the musical piece (rhythm, harmony, melody, and amplitude), factors that are intrinsic to the listener (meaningfulness and extra-musical associations), and “collative” factors (level of complexity and familiarity).35 The nature of self-selection makes it probable that the music would be meaningful and would have strong extramusical associations, factors that we considered would lead to both groups experiencing greater affective arousal. The musical selections were also based on familiarity; therefore, we could expect that the complexity of the pieces would be perceived as being low. Complexity addresses the predictability of the music to the listener. As the listeners’ familiarity with a musical piece increases, the perceived (but not the objective) complexity of the piece decreases as the piece becomes more predictable.33 If affective arousal contributes a source of explanation to the findings of this study, it appears that the effect of this constituent is group dependent. One possibility that warrants further study is that arousal may differentially affect the availability of attentional resources, perhaps serving as a source of resource depletion in the PD group.

The finding that the presence of concurrent music was detrimental to parkinsonian gait does not, however, negate the need for further research into the potential of using salient music as a tool in gait rehabilitation. Although the focus of this study was the impact of extrinsic and collative factors of the music on gait performance, a lack of control of intrinsic musical factors may have conceivably contributed to the detrimental effects of music observed in this study. The ability to synchronise cadence to musical tempo has been well documented in patients who suffer from a variety of movement disorders.7,8,34,35 It was not our intention in this study to replicate this proven phenomenon but instead to explore the effect of concurrent music on spatiotemporal parameters of gait by using music selections that were both meaningful and familiar to the listener. As such, music tempo was not controlled in this study. Tempo, however, has been identified as the single most important factor in shaping the listener’s response to asynchronous music.36 Therefore, it is a distinct possibility that the wide range of tempos experienced by each subject may explain the exacerbation of gait deficits that were shown by the PD group in the presence of music. Our current research aims to more clearly elucidate the effect of music salience on observed gait changes by examining the potential effect of training with familiar and enjoyable music that has a restricted tempo range, therefore acting as a salient auditory cue.

CONCLUSIONS

The gait performance of PD patients was detrimentally affected by concurrently listening to music while walking in the single-task situation, an effect that was further compounded in the dual-task context. We have interpreted these findings to imply that listening to music may be an attention-demanding activity for PD patients.

The findings of our study substantiate the available information on the multitask limitations exhibited by PD patients. A possible explanation for the adverse effect of concurrent tasks on gait patterning is that attending to a simultaneous task results in a decrease in available resource capacity and/or increased difficulty in appropriately allocating attentional resources. In this study, instructions were not provided regarding the direction of attention to the music; however, the use of self-selected music increases the likelihood that the musical pieces were significant and meaningful and would therefore attract the attention of the subject. These results have serious implications for patients who may be at greater risk of falls in multitask situations such as walking while talking in a complex environment.

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Suppliers
b. Microsoft Inc, 1 Microsoft Way, Redmond, WA 98052.
c. Apple Inc., 1 Infinite Loop, Cupertino, CA 95014.
d. The Mathworks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.
e. Van Aeken Software BVBA, Spoormakersstraat 63, 1000 Brussel, Belgium.
f. SPSS Inc., 233 S. Wacker Dr, 11th Fl, Chicago, IL 60606-6307.