Gait Training With Progressive External Auditory Cueing in Persons With Parkinson’s Disease

Matthew P. Ford, PT, PhD, Laurie A. Malone, PhD, Ilidiko Nyikos, MS, Rama Yelisetty, MS, C. Scott Bickel, PT, PhD


Objective: To investigate the progressively increasing external auditory cues during mobility training with persons with Parkinson’s disease (PD).

Design: Experimental.

Setting: General community.

Participants: Convenience sample of persons with PD (N=12) who walked independently.

Interventions: Gait training to external auditory cues was based on a participant’s comfortable walking pace. Training external auditory cue rates were increased if patients were able to maintain or increase stride length with increasing external auditory cue rates. Movement synchronization was not monitored during training. Participants trained for 30min/session, 3 sessions/wk, for 8 weeks.

Main Outcome Measures: Walking velocity, stride length, and cadence.

Results: Participants trained at a mean maximal rate of 157bpm. They showed a significant (P<.01) increase in walking velocity, stride length, and cadence after 8 weeks of training.

Conclusions: Walking velocity, stride length, and cadence can significantly improve when community-dwelling persons with PD participate in progressive mobility training.

Key Words: Parkinson disease; Rehabilitation.

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PARKINSON’S DISEASE AFFECTS approximately 6 million people around the world.1-3 Tremor, slowness of movement, poor balance, and decreased physical activity all contribute to impaired walking and functional mobility.4-11 People with PD tend to walk slower, with shorter steps, but a higher cadence.12-14 However, walking improves after participation in a structured mobility training program.15-18 For example, using a treadmill requires an individual to match stride length and cadence to the speed of the treadmill belt. Progressive increases in belt speed lead to increases in stride length, cadence, and as a result, walking velocity. Using a body weight–supported system can allow training at even higher speeds as the apparatus minimizes the balance demands of walking and the individual’s risk for falling is eliminated. Progression is guided by comfort level, overall safety, and ongoing assessments of patient’s ability to match the treadmill belt speed. Maximum training speed is identified when the stride length begins to decrease in order to keep up with the treadmill belt. Participants will take shorter steps or transition to a jog in an effort to keep up with the belt speed.

A second example of an effective mobility training program involves the use of an external auditory cue. An external auditory cue does not physically constrain leg movement, such as when walking over a moving treadmill belt; however, movement speed and amplitude is altered when an external auditory cue is present.19,20,33-36 Movement synchronizes with an external auditory cue in 2 ways.27 First, there is period synchronization when movement period (time between maximum excursion to maximum excursion) matches the period between 2 successive external auditory cues. The second type is phase synchronization. This is when the point in time of contact between the foot and ground is synchronized with onset of the external auditory cue. Period synchronization occurs within a few steps of the introduction of the external auditory cue. Phase synchronization is more difficult to achieve because foot-to-ground contact will occur just prior to or just after the onset of an external auditory cue.

During mobility training with an external auditory cue, period and phase synchronization may be monitored to ensure that a person’s walking is optimized as the training rate is increased. If a person is unable to synchronize movement with onset of the external auditory cue or its period, the external auditory cue rate will be lowered until synchronization occurs. An external auditory cue training threshold may be set a priori. Even though persons are not physically constrained by the external auditory cue, training at too high a rate may lead to small steps (length) at a high rate (cadence), an inefficient walking pattern. During a 3-week training program for persons with PD, with training rates (music beat) progressively increasing, Thaut et al25 set a training threshold of 130bpm, but also monitored movement synchronization. Training sessions were 30 minutes long with participants training 10 minutes at comfortable pace, 10 minutes at 10% higher than comfortable, and 10 minutes at 20% higher than comfortable. Each week the comfortable pace was reset at a rate 10% higher than the previous week. Therefore, each week the comfortable, fast, and very fast rates were higher than the previous week. This progressive training method, even with a training threshold, led to

List of Abbreviations

- **ANOVA**: analysis of variance
- **bpm**: beats per minute
- **PD**: Parkinson’s disease

From the Department of Physical Therapy, University of Alabama at Birmingham, Birmingham (Ford, Bickel); Department of Research and Education, Lakeshore Foundation, Homewood (Malone, Nyikos, Ford, Bickel); University of Alabama at Birmingham/Lakeshore Foundation, Homewood (Yelisetty), AL.

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Reprint requests to Matthew P. Ford, PT, PhD, Dept of Physical Therapy, SHP 334, School of Health Professions, University of Alabama at Birmingham, 1530 3rd Ave South, Birmingham, AL 35294, e-mail: mford@uab.edu

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significantly greater walking speed, stride length, and cadence compared with a similar group that trained without music.

A goal of mobility training should be to maximize stride length while walking at the fastest cadence possible. Interventions that increase these 2 variables will result in higher walking speeds. Yet walking speed has also been shown to improve when only cadence significantly increases after persons with PD train with an external auditory cue.27,28 In these 2 studies, participants were walking/training at a higher than comfortable walking rate, but movement (period or phase) synchronization was not monitored. It is possible that stride length did not significantly increase because participants were training at rates that could not synchronize with and increase stride length. That is, participants had to decrease stride length in order to keep up with the rate. Still, walking speed increased, and there currently is no evidence to suggest that training with external auditory cue with movement synchronization is best for overall improvements in walking function. Can walking improve if persons with PD train at external auditory cue rates significantly higher than what they can synchronize with? Accurate monitoring of movement synchronization requires sophisticated real-time assessment devices, which is unrealistic for everyday mobility training. We know that if both stride length and cadence increase, walking velocity increases. It is possible that caregivers or health care professionals could periodically time a person’s walking over a certain distance while counting the number of steps the person takes. These periodic measurements may serve as a guide for progressing a person who is walking with an external auditory cue. We hypothesize that if changes in walking velocity, stride length, and cadence are used as guidelines for training progression, walking velocity will significantly improve after training with an external auditory cue for 8 weeks.

METHODS

Participants

A convenience sample of 14 persons (age, 50–79y; 9 men, 5 women) with a medical diagnosis of idiopathic PD (Hoehn and Yahr I–III) agreed to participate in this study. Medical diagnosis was confirmed by participants’ neurologists. Two participants dropped out of the study because of increasing back pain with training; therefore, data reported here relate to the participation of 12 persons (table 1). Participants were included if they (1) were able to walk independently, (2) had no severe perceptual deficits, (3) had no complicating medical history such as cardiac or pulmonary disorders, and (4) had sufficient motivation to participate. All methods were approved by the institutional review board of the University of Alabama at Birmingham, and written informed consent was obtained from each person prior to participation.

Design

Pretraining and posttraining comfortable and fast walking speeds, stride length, and cadence were determined by taking the mean of 3 separate walking trials over 6m. Participants walked on a 9-m walkway with passive reflective markers placed on the 5th metatarsal and calcanei of both feet. Investigators allowed 1.5m on each end of the walkway for acceleration and deceleration. An 8-camera Vicon motion analysis system was used to determine the spatial and temporal parameters of participants’ walking. Heel strikes of each foot were determined by analyzing video of walking and marking the point in time where horizontal movement of the calcaneus marker had plateaued in the x-direction. Once heel strikes were determined over 6m, we used Vicon Nexus software to determine the spatial and temporal parameters of a walking trial.

Training took place on an indoor 200-m track at Lakeshore Foundation in Homewood, AL. Participants trained 30 minutes a session, 3 sessions a week for 8 weeks. Each was outfitted with a heart rate monitor and iPod and headphones for each training session. Training sessions consisted of 2 parts: (1) an evaluation period and (2) a training period (table 2). Training started at an external auditory cue rate (available in 5-beat increments from 60–165bpm) that approximated the comfortable cadence that was previously measured in the laboratory. For instance, if a participant’s mean comfortable cadence was 126 steps/min, they started their training at a cueing rate of 125bpm. Each participant was instructed to “step to the beat of the music.” During each training session participants’ walking velocity, cadence, and stride length were calculated 12 times (see table 2). To do this, investigators timed the participants as they walked over 1 of 4 premeasured 9-m segments marked on the track while counting the number of steps taken over that same distance. In addition, during the middle of each training session (evaluation period 2, between minutes 13 and 15), participants were asked to walk at a cueing rate 10bpm higher than the rate at which they had been training. Again, investigators measured walking velocity, stride length, and cadence in

<table>
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<tr>
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<th>Sex</th>
<th>Age (y)</th>
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<th>UPDRS Motor</th>
<th>Average Time</th>
<th>Target Heart Rate Zone (mean min ± SD)</th>
<th>PD Medications</th>
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<td>Ropinirole</td>
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<td>F</td>
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<td>29.27 ± 5.09</td>
<td>Pramipoxole</td>
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<td>11</td>
<td>28.25 ± 6.42</td>
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Abbreviations: F, female; M, male; UPDRS, Unified Parkinson’s Disease Rating Scale.

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order to determine whether the training rate should increase to this new cueing rate or remain at its previous rate (fig 1).

Previous studies25-28 have described methodology for progressing external auditory cue during mobility training. In these studies, participants were progressed a certain percentage above a comfortable cadence (e.g., 5%, 10%, and so forth). The increases were incremental, and often a ceiling training rate was used as a guide. For instance, persons would not train higher than a typical fast walking cadence or their previously determined fast cadence. In order to determine best a participant’s response to a particular cueing rate, we used walking speed, stride length, and cadence as guide to training progression (see fig 1).

Materials

Music rhythm rates were produced at the Center for Biomedical Research in Music at Colorado State University. Rhythm rates were constructed in increments of 5bpm ranging from 60 to 165bpm. Each tune had at least 5 separate parts: melody, chords, bass, percussion (multiple tracks), and the metronome. All parts were arranged to support the pulse of the music and were coordinated with the metronome. Typically the metronome click, chord, bass note, bass drum, and melody note (when possible) were sounded simultaneously. The melody notes that did occur on the beat were given accents (volume increases), and in general, all the parts were very staccato (as opposed to legato) to help define the pulse as precisely as possible, and with a short duration. The overall objective was to adapt the music to the pulse. All tunes are in the public domain.

Music was downloaded to iPods for use during training sessions. Participants wore the iPod on their arms and used headphones for listening.

Data Analysis

We calculated the mean walking velocity, stride length, and cadence without the constraint of music prior to training and posttraining. Differences between pretraining and posttraining were determined by taking the mean of 3 walking trials per each dependent variable. Mean values for walking velocity, stride length, and cadence were calculated for each of the 24 training sessions. Percent increases in training rhythm rate from session 1 to session 24 were also determined. Additionally, the percent change in training rhythm from session 1 to

<table>
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<th>Training Period</th>
<th>Evaluation Period 2</th>
<th>Training Period</th>
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<td>min 0–13</td>
<td>+10bpm (based on</td>
<td>min 15–30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>previous training</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>day)</td>
<td></td>
</tr>
<tr>
<td>2 measures taken</td>
<td>2 measures</td>
<td>2 measures taken</td>
<td>2 measures</td>
</tr>
<tr>
<td>between min 1 and 3</td>
<td>between min 10</td>
<td>between min 17 and 19</td>
<td>between min 27 and 30</td>
</tr>
<tr>
<td>and 3</td>
<td>and 12</td>
<td>and 19</td>
<td>and 30</td>
</tr>
</tbody>
</table>

NOTE. Total training period – 30 minutes = 1 session. This process was repeated for each of the 24 training sessions.
2-way ANOVA was also used to examine mean differences between training sessions. A Friedman ANOVA was performed to compare mean differences over the 24 training sessions. Separate Friedman ANOVAs were performed to compare mean z-score changes between sessions 1 to 6 and sessions 7 to 24.

### RESULTS

Comparing pretraining and postraining gait parameters, significant increases in comfortable walking velocity, stride length, and cadence ($P<.01$) (table 4) were found. There were also significant increases in fast walking velocity ($P<.04$), but increases in fast stride length ($P<.19$) and cadence ($P<.08$) were not statistically significant (see table 4). From session 1 to session 24, there was a 33% increase in the external auditory cue rate used during training. Participants trained at their age predicted target heart rate for a mean ± SD of 20.13±2.51 minutes per 30-minute training session (see table 1). Descriptive statistics revealed a 19% increase in walking velocity (1.28±.23–1.58±.28m/s), 15% increase in stride length (1.36±.20–1.46±.21m), and a 21% increase in cadence (110±8–129±13 steps/min) when comparing mean gait parameters at training session 1 to training session 24. A repeated-measures ANOVA showed significant main effects ($P<.01$) for the dependent variables walking velocity and cadence, but not stride length. A Bonferroni correction showed significant ($P<.01$) differences in velocity and cadence between training sessions 1 and 24 and 2 and 24. On average, participants reached their highest training rhythm by session 6 (table 5). Nonparametric statistics revealed a significant difference ($P<.01$) between training sessions for mean z-score differences. A comparison of the mean z-score changes revealed a significant difference between sessions 1 and 6 ($P<.01$), while there was not a significant difference between sessions 7 and 24 ($P<.47$).

### DISCUSSION

Participants with PD walked at significantly higher speeds, with longer strides and higher cadences after training with progressively increasing external auditory cues. These improvements are in line with previous investigations in which persons with PD trained at external auditory cue rates greater than their comfortable walking rate. In the previous studies, however, training occurred at a maximum rate of

<table>
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<th>Example 1: Training Progression</th>
<th>Example 2: Training Plateau</th>
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<td>Evaluation period 1</td>
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<td>Evaluation period 2</td>
<td>13–15</td>
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<tr>
<td>Training period 2</td>
<td>15–30</td>
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</table>

NOTE. (A) An example of z-score calculations for a participant who progresses 10bpm after evaluation during the training session. (B) An example of z-score calculations for a participant who has reached maximum external auditory cue training rate. The external auditory cue rate does not increase after evaluating a 10bpm increase. Participant walking (without music) data pretraining and posttraining at both comfortable and fast rates.
130bpm (baseline, 97bpm)\textsuperscript{25} and at a mean of 108bpm (baseline, 98bpm),\textsuperscript{26} much slower than the current investigation, in which participants trained at rates as high as 165bpm (baseline, 110bpm), with a mean maximal training rate of 157bpm.

The maximum and mean external auditory cue training rates were higher in this current project for 2 primary reasons. First, 8 of 12 of our participants were at Hoehn and Yahr level I or II (mean = 1.9). Thaut\textsuperscript{25} investigated 15 persons with PD with a mean Hoehn and Yahr of 2.4, while McIntosh et al\textsuperscript{26} studied 21 participants with a mean Hoehn and Yahr of 2.8 (including 3 subjects at Hoehn and Yahr level IV needing physical assistance during training and no subjects at level I). The participants in the current study were functioning at a higher level (see table 1), allowing them to train at higher rates under training progression guidelines (see fig 1). The second reason there were differences is that we did not limit training rate progression if participants could not synchronize with the training external auditory cue rate (see fig 1). In the current study, participants’ external auditory cue training rate increased at a rate of 10bpm when comparing the assessment with the training period (see table 2). Training progressed even if stride length decreased, provided participants were within 15bpm of the external auditory cue rate. A Friedman ANOVA of the data obtained during training sessions. Training progression guidelines allowed persons to train at higher external auditory cue rates even when stride length decreased. It is possible that participants trained at higher walking velocities using a higher cadence but relatively shorter stride length. When not constrained by an external auditory cue during the posttraining assessment, participants may have walked at higher velocity, with slightly lower cadence and higher stride length, compared with training sessions. One reason for the overall differences in stride length between walking with and without external auditory cue is that participants responded differently to progression of training over the 8 weeks. Six participants showed a slight increase in stride length and walking velocity with further training (past plateau), while 3 participants showed small decreases in walking velocity from the point of the training plateau to the final training session (see table 5). A z-score statistic was calculated and used to assess the training progression outlined in this 8-week program. The z-score represented the deviation of cadence from the corresponding external auditory cue rate. We determined the absolute value of the difference in z-scores between each of the 2 evaluation periods and training periods during every training session. A relatively large difference in z-scores between an evaluation and training period corresponded with a situation in which a participant was not ready to progress to higher external auditory cue (see table 3). Small z-score differences (see table 3) represented the point at which persons had reached a training plateau, and further increases only increased deviation between cadence and the external auditory cue rate. A Friedman ANOVA of the z-score differences showed that z-score differences were significant.

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<th>Identification no.</th>
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<th>Stride Length (m)</th>
<th>Cadence (steps/min)</th>
<th>Session 1</th>
<th>Walking Speed (m/s)</th>
<th>Stride Length (m)</th>
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</table>

Table 5: Mean Walking Velocity, Stride Length, and Cadence at Session 1, Plateau per Participant, and at Session 24.
greater during session 1 than during sessions 6 and 24. However, there was not a significant difference between sessions 6 and 24. This would indicate that the progression guidelines led to an ideal training rate very early in the 8-week program. Some participants reached a training plateau earlier, some later in the 8-week training period (see table 5). Currently there is no evidence to suggest what external auditory cue dosage is best for different stages of PD and walking abilities. Future investigations should examine progression of external auditory cue dosage relative to disease severity and predominance of motor symptoms.

**Study Limitations**

There are limitations to the results of this current study. First, this was a small convenience sample of active persons with mild to moderate PD symptoms. Walking is a common form of exercise for persons with mild to moderate PD, but this methodology should be investigated with persons with more severe PD and in line with more typical rehabilitation timelines (ie, 3wk of training vs 8wk). Another limitation of this study is that the music used was produced at rhythm rates atypical for that music piece. It is possible that the same effects could be achieved with a simple metronome versus a more complex musical piece. Last, the progression of external auditory cue rates was chosen arbitrarily. We determined a priori to advance participants in increments of 10bpm, and keep cadence within 15bpm of the training rate, but recognize that this may not be optimal for all participants. We believe that the ideal (ie, maximal stride length at maximal stride rate) external auditory cue rate for some participants was missed.

**CONCLUSIONS**

The results of this study show that walking velocity, stride length, and cadence can significantly increase with progressive increases in external auditory cue in persons with mild to moderate PD. Previous findings,25-28 and those of the current study, would suggest that if synchronization with an external auditory cue is not monitored during training, gait parameters should be, in order to maximize training effects on both stride length and cadence. A systematic assessment of stride length and cadence can serve as progression guidelines for clinicians who are working to improve mobility and/or health and wellness in persons with PD. One of the benefits of this approach to training is that it does not require a detailed assessment period and/or phase synchronization. Clinicians, or even caregivers, need only count steps and time for a person to walk over a given distance. Assuming that periodic doses of mobility training are necessary for maintaining improved walking function in persons with PD, ongoing investigations of methodology related to external auditory cue are warranted. Additional research in this area should include an investigation of the use of external auditory cue in persons with different severities of PD comparing the effects of training at more comfortable rhythm rates versus higher rhythm rates, as well as the effects of training over different periods (eg, 3wk vs 8wk). These comparisons should include assessments of not only walking speed, stride length, and cadence but also changes in heart rate during and after training.

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**References**

Suppliers
a. Vicon, 5419 McConnell Ave, Los Angeles, CA 90066.
b. Apple Inc, 1 Infinite Loop, Cupertino, CA 95014.