Effects of Long-Term Gait Training Using Visual Cues in an Individual With Parkinson Disease

Background and Purpose. In an attempt to improve the gait of people with Parkinson disease (PD), researchers have examined the effect of visual cues placed on the floor. These studies typically have used a single session of training with such cues and have not examined the long-term carryover of such training. In the present study, therefore, gait was analyzed during uncued, cued, and retention phases, each lasting 1 month. Subject. A 78-year-old woman who had been diagnosed with PD 12 years previously (Hoehn and Yahr classification of disability, stage III) volunteered for the study. Methods. During the initial uncued gait phase, the subject was required to walk a distance of 10 m as many times as she could in 30 minutes, 3 times per week for 4 weeks. During the 4-week cued gait phase, visual cues were placed on the floor along the 10-m walkway. The cues were initially 110% of the uncued step length and were later increased to 120%. Following this cued gait phase, the subject’s gait was recorded periodically for 1 month without cues available. Step length, gait speed, and 2-dimensional lower-limb kinematics were compared within and across the 3 experimental phases. Celeration lines were calculated for the initial uncued phase and then extrapolated across the cued training and uncued retention phases. Binomial tests were used to analyze the significance of changes from the initial phase of the experiment. Results. Step length (0.53–0.56 m) and gait speed (0.77–0.82 m/s) were essentially unchanged during uncued gait training after the first day; however, during the cued gait phase, gait speed improved, from 0.87 m/s to 1.13 m/s, as step length was increased with visual cues. Improvements in step length (0.68 m) and gait speed (1.08 m/s) were still evident 1 month following the removal of the cues. Analyses of angle-angle diagrams and phase-plane portraits revealed that training with visual cues increased hip and knee range of motion and engendered more stable motor control of the lower limb. Discussion and Conclusion. In contrast to previous studies in which the benefits of visual cueing were relatively short-lived, in this study, 1 month of gait training with visual cues was successful in establishing a lasting improvement in gait speed and step length while increasing the stability of the underlying motor control system. [Sidaway B, Anderson J, Danielson G, et al. Effects of long-term gait training using visual cues in an individual with Parkinson disease. Phys Ther. 2006;86:186–194.]

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Parkinson disease (PD) affects approximately 1% of people over the age of 65 years in the United States, with the rate increasing to 9% in men and 4.3% in women when people admitted to nursing homes are included. The underlying pathology involves a gradual degeneration of the gray matter within the basal ganglia, resulting in a declining production of the neurotransmitter dopamine by the substantia nigra. Dopamine, through its use by the basal ganglia, plays an important role in movement preparation and execution. People with PD typically have hypokinesia, resting tremors, episodes of freezing, and a stooped posture. With disease progression, gait is affected, with the characteristic shuffling pattern resulting in decreased stride length and gait speed. Decreased arm swing, increased double-limb support, and decreased lower-extremity ranges of motion also are noted. These gait deficits are perhaps the most functionally debilitating symptoms of PD. Therefore, it is not surprising that the treatment of people with these gait deficits has received considerable attention from clinical researchers.

Pharmacologic therapy is particularly effective in the early stages of the disease, with levodopa being the most prevalent medication prescribed. Unfortunately, such medication provides only relatively temporary relief of symptoms. At 5 to 8 years after the initiation of levodopa therapy, gait hypokinesia reemerges. Given the decreased responsiveness to pharmacologic agents with time, researchers have explored rehabilitation options that might supplement traditional pharmacologic therapy.

One therapeutic technique that has attracted a notable amount of attention recently focuses on the use of external cues. Such cues have included instructional, auditory, visual, and cutaneous stimuli. During normal movement, it is believed that the basal ganglia, in conjunction with the supplementary motor area, trigger the performance of sequential movement components. This internal cueing mechanism, however, is disrupted in PD by the basal ganglion pathology; therefore, it has been hypothesized that the improvement seen with the use of external cues is attributable to such cues serving to bypass dysfunctional movement pathways in the basal ganglia.

Martin was one of the first researchers to document the facilitating effect of visual cues on parkinsonian gait. In his influential work, Martin placed lines on the floor oriented in a variety of directions along a walkway. He noted that the most effective arrangement was placement of the cues perpendicular to the direction of gait and spaced one step length apart. Since this seminal work, many experiments have replicated Martin’s findings of increased gait speed and step length with the application of visual cues. Such work, however, typically has used a relatively short session of training with visual cues. For example, in a series of experiments by Morris et al, subjects completed five to eight 10-m walks with visual cues present; in their later work, subjects completed 10-m walks for 20 minutes. Also somewhat problematic in terms of clinical applicability is the fact that no long-term retention tests have been conducted to determine how long the beneficial effects of visual cues alone last once they are no longer present.

To our knowledge, the only systematic study of gait after immediate retention was conducted by Morris et al. In this work, the researchers analyzed the effect of a 20-minute training session over a retention period of 2 hours. The improvements in gait were found to last up

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Dr Sidaway provided concept/idea/research design, writing, data analysis, and the subject. All authors provided data collection.

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to the end of the 2 hours of testing, as long as a secondary task was not introduced. They also reported that gait had reverted to baseline performance by the following day. Following an extensive review of the cueing literature, Rubinstein and colleagues also noted the absence of studies examining multiple-session interventions, although they noted that some studies embedded cueing techniques within multiple sessions of more traditional therapy.

To more thoroughly assess the clinical utility of visual cues in the treatment of parkinsonian gait, a long-term training regimen needs to be analyzed. Following such training, delayed retention tests should be conducted to determine the time course for the extinction of any benefits derived from the training. Thus, in the present study, three 1-month experimental phases—uncued gait, visually cued gait, and uncued gait in retention—were examined in an individual with PD. The initial uncued gait phase was included to determine whether simply extra practice walking without visual cues would improve the subject’s gait prior to the imposition of training with visual cues. Without this phase, we would not be able to determine whether improvements seen in the cued phase were attributable to the cues or just more practice walking. We hypothesized that this initial phase would not generate significant improvement in gait but that the imposition of visual cues would increase speed while present. If the use of these cues created a lasting benefit, then this benefit would be reflected in the uncued retention tests. We believe that this experimental protocol better assesses the clinical potential of visual cues in improving gait in people with PD than experiments that have used a single session of training with visual cues.

**Method**

**Subject**

The subject recruited for this study was a 78-year-old woman who had been diagnosed with PD 12 years ago (Hoehn and Yahr classification of disability, stage III). The subject was taking carbidopa/levodopa at doses of 25/100 mg and 50/200 mg (Sinemet CR®) at regular intervals throughout the day. Prior to the experiment, the subject could walk short distances in the community without an assistive device; however, for longer distances, she would use a wheelchair pushed by her husband. The subject wore glasses, had intact sensation in her lower extremities, and had hip, knee, and ankle ranges of motion within functional limits. She could recall falling only once in the year prior to the start of the experiment. The subject signed an informed consent statement prior to any testing.

**Procedure**

The experiment comprised 2 training phases and a retention phase, each lasting 1 month. In the initial training and final retention phases, the subject walked without any cues present, but during the second training phase, visual cues were provided; therefore, the experimental protocol essentially followed an A-B-A design. In the first phase, the subject was required to walk uncued for up to 30 minutes 3 times per week for 4 weeks, on the same days of the week and at the same time of day. During each 30-minute session, the subject was required to repeatedly walk, at her own freely chosen speed and step length, a distance of 10 m. The subject was free to rest at any time she wanted by sitting on chairs placed at the ends of the 10-m walkway. Thus, the number of 10-m walks that the subject made varied from day to day because of factors such as fatigue and motivation. All phases of the experiment were conducted during the subject’s “on phase,” approximately 1 hour after she took her medication, and were always carried out on a large gymnasium floor that was devoid of any obvious markings and distractions.

The subject wore a gait belt at all times and was guarded on each trial, although at no time did she need any assistance. Reflective markers were attached to anatomic landmarks on her right side so that a video-based kinematic analysis could be performed. Markers were attached to the subject’s acromion, greater trochanter, lateral femoral condyle, lateral malleolus, shoe heel, and head of fifth metatarsal. A video camera was placed 12 m away, perpendicular to the direction of walking, in order to record the subject’s gait pattern in the sagittal plane.

In addition to videotaping each trial, the time taken to walk the 10 m was recorded with a stopwatch, and the number of steps taken was counted. The ends of the 10-m walkway were marked with 2.54-cm-wide (1-in-wide) white athletic tape on the floor. The subject was required to start and finish a few steps before and after these marks in an attempt to ensure that she was walking at a constant speed throughout the 10 m. Mean gait speed and step length were calculated from the recorded time and the number of steps counted.

Following completion of this initial uncued phase, the subject underwent the 4-week training phase, in which she again walked with the same protocol as during the first phase. All procedures during the training phase were identical to those during the initial phase apart from the addition of visual cues, which were placed on the floor the entire length of the 10-m walkway. The cues were 1-m strips of 2.5-cm-wide blue masking tape placed orthogonal to the direction of walking. These cues were present for every recorded walk during this second phase of the experiment. The distance between the
strips was initially 110% of the mean step length calculated from the last uncued session. After 5 days of training with the cues 110% apart, the distance was increased to 120% of the uncued mean step length for the remainder of the visually cued training phase. The subject was instructed at the beginning of each day to step over these cues during her walks.

After completing the 4-week visually cued training phase, the subject entered the retention phase, in which the visual cues were removed. The retention phase was included to assess whether any changes that occurred as a result of the visually cued training phase remained after removal of the visual cues. The subject’s gait was analyzed 2, 5, 9, 16, and 30 days following completion of the visually cued training phase. In each retention test, the subject was required to walk 10 m 10 times.

Data Analysis
The videotape records were digitized at 60 Hz by use of a Peak Performance computerized video analysis system. The mean gait speed and step length data were calculated for the first 10 trials completed on each day for all phases of the experiment. To determine whether training with visual cues improved the subject’s gait beyond that achieved with uncued gait training, a celeration line slope was calculated for the initial uncued gait training phase and then was extrapolated across the cued gait training phase. This celeration line also was extended into the retention phase of the experiment to determine whether the performance of the subject after removal of the visual cues was different from that during the initial phase of the experiment. Celeration lines were calculated for both step length and gait speed. Celeration lines were computed by use of the split-middle method, with the null hypothesis of no significant difference in gait step length or speed being tested with a binomial test.24

Results
In the uncued and visually cued training phases of the experiment, the subject made as many 10-m walks as she could in the 30 minutes allotted for practice. She could rest on chairs at the ends of the walkway whenever she wanted. Consequently, the number of walks that she made in the 30 minutes varied from day to day. During the experiment, the least number of walks that the subject made was 14, and the greatest number was 45. The average number of walks in the initial uncued gait phase was 30, and in the cued gait phase, the average number was 33. For comparison across days and phases of the experiment, gait parameters from only the first 10 walks on each day were compared.

Uncued Gait Phase
The effect of uncued gait training on step length is shown in Figure 1. The graph shows a relatively large increase in step length from the first session ($X = 0.48 \text{ m}$, SD = 0.04) to the second session ($X = 0.54 \text{ m}$, SD = 0.02), but from then on, step length remained quite stable, varying between 0.53 and 0.56 m. The celeration line plotted through these data had a calculated slope of $y = 0.0001x$. This line is shown extrapolated across cued gait and retention phases in Figure 1.

Examination of gait speed revealed a pattern of change similar to that for mean step length (Fig. 2). Following day 1 ($X = 0.70 \text{ m/s}$, SD = 0.05), gait speed across days was essentially stable, varying between 0.77 and 0.82 m/s. The celeration line plotted through the speed data in this uncued gait phase had a calculated slope of $y = 0.0013x$. This line is shown extrapolated across cued gait and retention phases in Figure 2.

Cued Gait Phase
Mean step length during the cued gait phase is shown in Figure 1. Recall that during this training phase, step length was regulated by the cues placed on the floor. For the first 5 days of training, the cues were 110% of the subject’s step length at the end of the uncued gait phase. For the remaining 7 days of the cued phase, the distance...
between the cues on the floor was increased to 120% of the subject’s step length at the end of the uncued phase. The subject was consistently able to step over the cues throughout the training phase, resulting in mean step lengths of 0.59 m (days 1–5) and then 0.67 m (days 6–12). To determine whether the pattern of step length data in the uncued gait phase was statistically different from the pattern of data in the uncued gait phase, a binomial test was conducted with the extrapolated celeration line calculated from the first phase of the experiment. This analysis indicated that step length was significantly greater ($P<.001$) during cued gait than during uncued gait.

Examination of gait speed during cued gait revealed a general increase in speed across this phase from 0.87 m s$^{-1}$ (SD=0.04) in session 1 to 1.13 m s$^{-1}$ (SD=0.04) in session 12 (Fig. 2). To determine whether gait speed during cued gait was statistically different from that during uncued gait, a binomial test was again conducted. Like the analysis for step length, this analysis indicated that gait speed was significantly greater ($P<.001$) during cued gait than during uncued gait.

**Retention Phase**

The mean step length during the retention phase, when visual cues were no longer available, is shown in Figure 1. Step lengths 2 days ($\bar{X} = 0.59$ m, SD=0.03) and 5 days ($\bar{X} = 0.59$ m, SD=0.06) after the termination of cued gait training showed a large decrease from that found in the last session of training ($\bar{X} = 0.67$ m). However, mean step length within the final 3 sessions of retention testing showed an increase from that found in the first 2 sessions and was similar to that found at the end of cued gait training (day 9: $\bar{X} = 0.67$ m, SD=0.05; day 16: $\bar{X} = 0.66$ m, SD=0.05; day 30: $\bar{X} = 0.68$ m, SD=0.04). The pattern of step length data for the retention phase was significantly different ($P<.001$) from that for the first phase of uncued gait training, as determined by a binomial test conducted on the extrapolated celeration line.

A similar pattern was found for gait speed during the retention phase (Fig. 2). Speed on retention phase days 2 ($\bar{X} = 0.86$ m s$^{-1}$, SD=0.05) and 5 ($\bar{X} = 0.87$ m s$^{-1}$, SD=0.04) was lower than that on days 9 ($\bar{X} = 1.06$ m s$^{-1}$, SD=0.06), 16 ($\bar{X} = 1.01$ m s$^{-1}$, SD=0.11), and 30 ($\bar{X} = 1.08$ m s$^{-1}$, SD=0.05). Gait speed was found to be significantly greater than that exhibited during the first uncued gait phase when the data were compared by use of a binomial test conducted on the extrapolated celeration line.

**Kinematics**

The analyses described above showed clear changes in step length and gait speed as a result of the use of visual cues. In an attempt to determine how the subject generated these parametric changes in gait, 2-dimensional kinematics of the lower extremities were examined. Such analyses provide a vast amount of information. For brevity, only a comparison between 2 key experimental days is included here, day 2 of the uncued gait phase (after the subject was familiar with the procedures) and the fifth and last retention session (day 30), on which again no cues were present.

To illustrate the changes in lower-extremity coordination between these 2 days, an exemplar hip-knee angle-angle diagram for 3 strides of the right leg is presented in Figure 3. An angle-angle diagram plots the angle of one joint against the angle of another across time and so provides a parsimonious representation of the coordination between the 2 joints. A single representative trial was examined, as this procedure facilitates correlation with related biomechanical events that averaging across a series of trials would prevent. The trial chosen was the fifth walk that the subject made on each day. Figure 3 clearly shows that, during the retention phase, both the hip and the knee had greater ranges of motion than during baseline. The maximal hip flexion and extension consistently increased by approximately 5 degrees and there was generally a 15-degree increase in knee flexion during the swing phase. This angle-angle plot also illustrates the change in variability in the coordination of the
2 joints. In the retention phase, the pattern was much smoother, particularly during the stance phase (left-hand side of Fig. 3 between heel-strike [HS] and toe-off [TO]), whereas the overall shape more closely resembled the typical heart-shaped pattern seen in neurologically intact people.

Another way of illustrating the stability of the coordinative function generated by the motor system is to examine the hip and knee joints separately in state space. Figures 4 and 5 display such phase-plane portraits for the hip and the knee, respectively. In a phase-plane portrait, displacement (joint angle) is plotted against its first derivative (joint angular velocity), enabling examination of where the joint is in space and how fast it is moving at any point in the skill, thus giving a unique insight into the control of the joint.25 It is evident from the plots shown in Figures 4 and 5 that the control of the knee and particularly of the hip was significantly more stable during retention testing than during baseline testing. The angular velocity profiles during retention testing showed much less variation from stride to stride, especially for the hip, indicating more stable motor control across strides.

Discussion

The use of external cueing techniques to improve parkinsonian gait has received considerable attention recently.20 Some studies11,12 have established that visual cues placed on the floor can temporarily improve various gait parameters. Despite the recent interest in the use of such cues, there has been no study specifically investigating the effect of the long-term use of visual cues. The present study is an initial attempt to examine the possible retention of gait improvements engendered by 1 month of training with such cues in an individual with PD.

The first phase of the experiment required the subject to walk 3 times per week for 4 weeks, because it was not known whether practice walking without visual cues would lead to significant improvements in gait. The data clearly showed that, after the first day of uncued gait training, gait speed and step length remained essentially unchanged across training sessions. The increase in gait performance from the first training session to the second training session was probably the result of the subject becoming familiar and comfortable with the experimenters and procedures. Notwithstanding this initial increase in performance, simply practicing walk-
ing did not seem to systematically improve the gait parameters analyzed in the study.

Following the establishment of consistent performance during uncued gait training, the subject was again required to complete 10-m walks 3 times per week for 4 weeks. During this next phase of this experiment, however, the subject was required to step over visual cues, initially spaced at 110% and later spaced at 120% of her baseline step length. The subject was successful in adjusting her step length to meet these task constraints. As a result, her gait speed showed a consistent increase across training days and was statistically greater than that found during uncued gait training sessions.

The final phase of the experiment was designed to determine how long the improvements in gait established during cued gait training would last once the visual cues had been removed. The first retention test was conducted 2 days after the end of cued gait training. There was a 2-day interval before the next retention test, followed by a 3-day interval. The final retention tests were conducted 16 days and then 30 days later. Thus, the retention tests were gradually reduced in frequency over a 1-month interval.

The statistical comparison of gait speed and step length across experimental phases clearly showed that the improvements established during the cued gait phase were largely retained over the month during which performance without visual cues was analyzed. It is clear, however, that the data for both gait speed and step length indicated substantially poorer performance on the first 2 retention tests than on the remaining retention tests. It should be noted that during the first week of retention testing, the subject reported that she was not feeling well and had decided to adjust her medication schedule. After the subject revealed that she was doubling her regular medication dosage, she was encouraged to consult her primary care provider. Prior to the third retention test, the subject reported visiting her physician and returning to the original medication schedule and dosage. The final 3 retention tests were conducted without any further changes in her medication regimen. We believe that the markedly poorer performance exhibited during the first 2 retention tests was probably the result of inappropriate medication dosage and not the result of the removal of visual cues. Thus, we attributed the improvement in performance from the second retention session to the third retention session to the change in medication dosage, as the subject returned to her normal medication regimen, suggesting that the previous inappropriate medication schedule masked the subject’s real ability.

Kinematic analyses revealed that the subject increased her step length primarily by increasing both flexion and extension range of motion at the hip. Similar increases in hip range of motion have been reported to contribute to improved step length and gait speed following the administration of levodopa. Increased knee flexion also has been reported during the on phase in people with PD. The present study also revealed increased knee flexion during the swing phase, which lowered the moment of inertia of the lower extremity and therefore enabled an increase in the angular velocity of the whole limb. The increased angular velocity of the hip and knee joints shown in the phase-plane portraits, along with the increased step length, contributed to the increased gait speed during the retention testing. The phase-plane plots also highlight the increased stability of motor control that was engendered by the month of training with visual cues.

The underlying mechanism by which long-term training with visual cues facilitated improvements in gait speed and step length could not be addressed by the present experiment. Previous research suggested that the hypokinesia seen in people with PD may be the result of a disruption in the connections between the basal ganglia and the supplementary motor area leading to the inad-
equate generation of internal cues.\textsuperscript{14} Alternatively, it is possible that the generation of motor set–related activity in the basal ganglia is disrupted by a reduction in dopamine levels.\textsuperscript{14} In reviewing these possible mechanisms, Morris et al\textsuperscript{18} concluded that because people with PD retain the ability to modulate gait cadence, the reduced step length seen in PD is probably attributable to an inadequate motor set for gait. Postulating a different mechanism, Azulay and colleagues\textsuperscript{28} hypothesized that visual cues serve as moving targets, activating the cerebellar visual-motor pathway. This hypothesis was based on their finding that visual cues were not effective in improving gait under stroboscopic illumination. Stroboscopic illumination functions to prevent the cues on the floor from generating any optic flow. If this is indeed the case, then it appears from the present experiment that the long-term use of visual cues during gait can somehow cause a change in the control of gait from the cortical-motor pathway to the cerebellar visual-motor pathway. This change may be capable of supporting improvements in gait for at least 1 month following removal of the cues.

The improvements in gait performance were measured only in the experimental setting; therefore, the transfer of such improvements to walking outside of the gym- nasi um was not assessed. It is interesting, however, that during the initial phase of the experiment, the subject’s husband would push her the approximately 75 m from the parking lot to the gymnasium in a wheelchair, but midway through the cued gait phase, the subject chose to push her husband to the gymnasium in her wheelchair every day. The subject was very proud of the improvement in her walking ability and believed that the cued gait training significantly affected her everyday walking ability.

**Conclusion**

We found that 1 month of gait training with visual cues established a lasting improvement in gait speed and step length while increasing the stability of the underlying motor control system responsible for gait. These results, albeit obtained with only one subject, are clinically significant and worthy of further investigation. It is clear that the effect of long-term training with visual cues should be investigated with a larger sample. Such therapeutic training may prove to be a valuable adjunct to traditional pharmacologic treatment of parkinsonian gait.

**References**


