J. Phys. Ther. Sci.
24: 553–556, 2012

Augmented Feedback Using Visual Cues for Movement Smoothness during Gait Performance of Individuals with Parkinson's Disease

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Abstract. [Purpose] The purpose of this study was to investigate the effect of visual cues on movement smoothness during gait performance by individuals with idiopathic Parkinson's disease (PD). [Subjects and Methods] Eighteen patients with symptoms of idiopathic PD were recruited into the study. The mean age of the subjects was 65.1 years, and the mean post-disease period was 71.3 months. The gait performance was analyzed in this study under 2 different conditions, free walking and visual cue walking. To determine the effect of visual cues on the gait performance of PD patients, we collected spatiotemporal and kinematic parameters using a three-dimensional motion analysis system. [Results] Spatiotemporal parameters significantly improved during gait performance with visual cues compared to free walking. The presence of visual cues also resulted in significantly improved peak-to-peak angular displacement of the ankle, hip, and pelvis as well as movement smoothness in the lower extremities. [Conclusion] Our results suggest that augmented feedback using visual cues improves the deficit in kinematic parameters, and improves movement smoothness in the lower extremities of individuals with PD.

Key words: Parkinson's disease, Smoothness, Visual cue

(This article was submitted Dec. 16, 2011, and was accepted Feb. 18, 2012)

INTRODUCTION

Parkinson's disease (PD) affects approximately 6 million people worldwide, and is the most common progressive, neurodegenerative disease after Alzheimer's disease[1)]. Primary motor impairments of PD are tremor, slowness of movement, poor balance, and decreased physical activities, all of which contribute to impairments in walking and functional activities. This ultimately leads to an increase in falls, loss of independence, and immobility[2)].

Visual information, along with proprioception and vestibular information, plays an important role in human gait control. Visual information is essential for detecting and identifying sensory information from the surrounding environment, enabling appropriate spatiotemporal anticipation before initiating and completing movement. Vision also guides gait during navigation to destinations that are not visible at the start[3)].

During gait performance analysis, individuals with PD exhibit impaired timing, sequencing, and spatial organization of different segments. Previous studies have investigated various rehabilitation strategies using sensory cues for their impact on gait and falls of PD patients[4)]. Studies have shown short-term improvements in parkinsonian gait when external cues are provided (visual or auditory) or when verbal instructions to increase step length are given[5)]. However, few studies have investigated the effect of these factors on movement smoothness during gait performance.

The purpose of this study was to investigate the effect of visual cues on movement smoothness during gait performance by individuals with idiopathic PD. This study quantified the movement smoothness of PD patients during gait performance and assessed how smoothness changed, with or without visual information.

SUBJECTS AND METHODS

Eighteen patients who had symptoms of idiopathic PD participated in this study. Subjects were included if they (a) had been diagnosed with idiopathic PD more than 6 months ago, (b) had been prescribed PD-related medication, (c) were able to walk distances of 20 m repeatedly without assistance, (d) had no vision or visual field disease, and (e) were able to discriminate colors. Subjects were excluded from the study if they had a history of any other neurologic disorder, an orthopedic disorder, or a cardiopulmonary problem that would affect their ambulatory or balance ability. In addition, we excluded patients with cognitive deficits that would prevent conduct of the procedures used in this study. Prior to recruitment of the participants, approval for the

Table 1. General characteristics of the Parkinson's disease patients (N=18)

Characteristics	Subjects
Sex (males/females)	13/5
Age (yrs)	64.0 ± 7.7[a]
Height (cm)	164.7 ± 7.3
Weight (kg)	63.6 ± 7.7
Leg length (cm)	82.7 ± 4.9
Knee diameter (cm)	10.1 ± 0.6
Ankle diameter (cm)	7.5 ± 0.5
Post-disease duration (mo)	71.3 ± 43.6
Hoehn & Yahr Stage (2/2.5/3)	9/2/7

[a]mean ± standard deviation

study protocol was obtained from the S. Veterans Hospital Institutional Review Board. Table 1 describes the general characteristics of the PD patients.

Gait performance was analyzed in this study under 2 different conditions: (1) free walking at a self-selected comfortable speed; and (2) visual cue walking along a walkway, which had transverse red-colored tapes stuck on the floor at intervals corresponding to the step length of subjects, matched for leg length, age, and gender. For free walking, participants walked along the midline of a 12-m walkway. Before initiating gait for walking with visual cues, participants were verbally asked not to step on the red lines; then, they performed visual cue walking in the same manner as free walking.

To determine the effect of visual cues on gait performance of PD patients, we collected spatiotemporal and kinematic parameters using a three-dimensional motion analysis system and Workstation software (Oxford Metrics Inc., London, UK). Data collection was conducted at the Gait Analysis Research Laboratory in the S. Veterans Hospital. A five infrared camera VICON 512 system was utilized to obtain spatiotemporal data at 60 Hz. A total of 15 spherical reflective surface markers were placed on bony landmarks according to the guidelines of the VICON "plug-in-gait" model marker set. Data were collected in 5 successive trials under each condition, and the mean value of these 5 trials was used for data analysis and interpreting subjects' performance.

We examined spatiotemporal parameters, such as stride length, step length, cadence, ratio of single and double-support periods, and walking velocity. In addition, kinematic parameters, such as pelvic movement and hip, knee, and ankle joint angles in the sagittal plane were also measured. The kinematic parameters were used for calculating movement smoothness (third derivatives of the joint angles: units: degree/s^3). Zero-crossing is the point where the sign of a function changes and is represented by the crossing of the axis in a graph of the function. Counting zero-crossings is a method used in movement processing to estimate the fundamental frequency of movement. In this study, we calculated the number of zero-crossings in the sagittal plane motion of the hip, knee, and ankle joints from initial contact to next initial contact during gait performance. The paired t-test was used to explore the difference between the gaits with and without visual cues. Statistical significance was accepted for values of $p<0.05$. The paired t-test was also performed to compare changes in each of the smoothness metrics during gait performance with or without visual cues.

RESULTS

Gait velocity, stride length, and steps per minute significantly improved under the visual cue condition compared to the no visual cue condition. However, double limb support did not significantly improve under the visual cue condition (Table 2). During gait performance with visual cues, the peak-to-peak flexion-to-extension angular displacement significantly increased in the hip joint and the peak-to-peak dorsiflexion-to-plantarflexion angular displacement significantly increased in the ankle joint. However, the peak-to-peak flexion-to-extension angular displacement did not significantly improve in the knee joint (Table 2). The number of zero-crossings significantly decreased in peak-to-peak angular displacements of the ankle, knee, and hip joints (Table 3).

DISCUSSION

The main findings of this study were that patients with PD exhibited greater improvements in cadence, stride length, and gait velocity with visual cues than without. Also, angular displacements of the ankle, hip, and pelvis were altered during gait performance with and without visual cues. However, improvement in movement smoothness of the ankle, knee, and hip was higher with visual cues than without.

Gait of patients with PD is significantly slower than that of age-matched healthy individuals and is characterized by decreased stride length and increased double-support periods[6–10]. However, cadence generally increases more in PD patients than in age-matched healthy people because of PD patients' shuffling or festinating gait[11, 12]. The primary reason for PD patients' slower gait velocity decreased stride length despite the increased cadence. In this study, the lower gait velocity of the patients with PD was consistent with the results reported in previous studies.

In the PD population, gait performance is mainly affected by characteristics such as bradykinesia, hypokinesia, and akinesia[13, 14]. Bradykinesia is related to slowness or difficulty in performing some simultaneous or repetitive motor acts[1]. Hypokinesia refers to a slowness of gait characterized by a shortened step length and decreased foot clearance[15]. Therefore, patients with bradykinesia and hypokinesia typically show decreased gait velocity and stride length and may show increased cadence to compensating for this shortened stride length. The gait of PD patients is commonly described as "shuffling gait." The results of this study suggest that visual cues can be used to improve gait velocity, stride length, and compensatory pattern.

This study examined the ankle, knee, and hip joint angles in the sagittal plane during gait performance with or without visual cues. PD patients typically display limited

Table 2. Kinematic parameters of gait with and without visual cues of the Parkinson's disease patients (N=18)

Characteristics	Gait with no cues	Gait with visual cues
Cadence (steps/min)	104.9 ± 14.4[a]	78.8 ± 15.9*
Stride length (cm)	86.1 ± 23.4	100.6 ± 2.8*
Gait velocity (m)	0.8 ± 0.2	0.7 ± 0.1*
Single support/Double support	1.3 ± 0.2	1.3 ± 0.3
Peak-to-peak displacement		
Ankle dorsiflexion-plantarflexion	21.1 ± 5.7	26.2 ± 6.3*
Knee flexion-extension	41.2 ± 9.8	38.2 ± 13.2
Hip flexion-extension	34.1 ± 9.0	39.1 ± 4.8*
Pelvic tilting	3.6 ± 1.8	6.2 ± 2.9*
Pelvic rotation	8.2 ± 4.6	11.6 ± 4.7*
Pelvic oblique	4.2 ± 1.8	5.4 ± 2.2*

[a]mean ± standard deviation. *$p<0.05$

Table 3. Smoothness of movement in gait with and without visual cues of the Parkinson's disease patients (N=18)

Movement	Gait with no cue	Gait with visual cue
Ankle dorsiflexion-plantarflexion	8.8 ± 1.5[a]	5.5 ± 1.5*
Knee flexion-extension	8.9 ± 1.7	6.2 ± 1.7*
Hip flexion-extension	8.9 ± 1.7	6.2 ± 1.7*

[a]mean ± standard deviation, number of zero-crossing. *$p<0.05$

hip movement from midstance to preswing, decreased knee extension through stance, and decreased plantarflexion following terminal stance. There is often decreased initial knee flexion and hip flexion from initial swing to midswing and a lack of knee extension in terminal swing[15)]. Visual cues affected angular displacement in this study, and movement was made smoother during gait performance in the visual cue condition than in the no visual cue condition. Postural control during locomotion requires the integration of multiple sensory and motor pathways so that the central nervous system can coordinate the postural and movement components of the task[16)]. Previous studies have shown that nervous system problems may occur with aging, and this may lead to less smooth movement[17–19)]. These previous studies also suggested that movement smoothness is a result of learned coordination, and increases with recovery, because the segmented nature of a stroke patient's arm movement can be attributed to a deficit in interjoint coordination[18, 19)]. Therefore, the results of the present study suggest that visual cues improve a deficit in interjoint coordination in the lower extremities.

Although previous studies on gait training with visual cues have shown positive findings, our study did not fully confirm the training effect of visual cues[4, 20)]. Another limitation is that this study was performed during the participants' "on" state of medication, even though PD patients might show greater gait disturbance in the "off" state. In addition, our sample size was small. This was because a larger sample size would have made it difficult to conduct kinematic analysis, which requires extra-attention to safety and trained assistants to perform the biomechanical tests.

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