Influence of visual feedback sampling on obstacle crossing behavior in people with Parkinson's disease

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ABSTRACT

The purpose of the current study was to investigate the role of visual information on gait control in people with Parkinson’s disease as they crossed over obstacles. Twelve healthy individuals, and 12 patients with mild to moderate Parkinson’s disease, walked at their preferred speeds along a walkway and stepped over obstacles of varying heights (ankle height or half-knee height), under three visual sampling conditions: dynamic (normal lighting), static (static visual samples, similar to stroboscopic lighting), and voluntary visual sampling. Subjects wore liquid crystal glasses for visual manipulation. In the static visual sampling condition only, the patients with Parkinson’s disease made contact with the obstacle more often than did the control subjects. In the successful trials, the patients increased their crossing step width in the static visual sampling condition as compared to the dynamic and voluntary visual sampling conditions; the control group maintained the same step width for all visual sampling conditions. The patients showed lower horizontal mean velocity values during obstacle crossing than did the controls. The patients with Parkinson’s disease were more dependent on optic flow information for successful task and postural stability than were the control subjects. Bradykinesia influenced obstacle crossing in the patients with Parkinson’s disease.

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1. Introduction

Walking on level ground has been well described in the literature for people with Parkinson’s disease (PD) [1,2], but this kind of task has an important ecological limitation; these individuals do not walk on even terrain all of the time. They must adapt their locomotor movements to the different surface characteristics they encounter in everyday activities. When they are unable to adequately avoid an obstacle and they trip, this can lead to a fall. Tripping over obstacles has been identified as one of the major causes of falls in people with PD [3].

Several previous studies have reported foot clearance difficulties during obstacle crossing by people with PD [4–7], but none has investigated the role of visual information on their control of step adjustments while crossing obstacles. Optic flow, in particular, experienced during the act of self-propulsion, is used to control walking speed and the estimation of time to contact [8,9]. Also, it has been observed that optic flow helped to improve the gait parameters of people with PD, crossing over a striped floor [10]. Since individuals use visual information, relative to obstacle position and size, to plan and control their adaptive gait [11,12], it is important for investigators to understand the influence that visual feedback and optic flow information have on the locomotor behavior of people with PD as they cross obstacles.

Individuals’ dependence on visual input to guide them through successful obstacle avoidance can be described via the concept, voluntary visual sampling [13]. In our previous study, which employed this paradigm of vision manipulation [14], PD patients and healthy subjects required the same amount of visual information (i.e., total duration of visual samples) while they walked on even terrain. Because the required amount of visual information is directly influenced by environmental complexity [13], and because people with PD are more dependent on visual information due to proprioceptive deficits [15,16], the voluntary visual sampling paradigm can help us understand how people with PD use visual information for space-time adjustments during obstacle avoidance. To our knowledge, this is the first study to explore this paradigm during obstacle crossing by PD.

The aim of the current study, therefore, was to investigate the role of visual information on control, in people with Parkinson’s disease, as they crossed over obstacles of different heights. We hypothesized that people with PD would be more dependent on...
optic flow during the crossing of obstacles than would their healthy counterparts.

2. Methods

2.1. Participants

This study adhered to the guidelines of the Declaration of Helsinki, and was approved by the Local Ethics Committee (Process #2688/2007). Twenty-four subjects volunteered to participate in the study, including 12 people with idiopathic PD, and 12 neurologically healthy individuals (CG). The CG individuals were pair-matched with people with PD by age, body height, body mass, and gender. All had participated in a previous study by our group (that is, the data were collected at the same time and separated into different studies) [14].

A clinical assessment was performed by a neuropsychiatrist in order to test patients on the Hoehn and Yahr Rating Scale (H&Y) [17], the Unified Parkinson's Disease Rating Scale [18], and the Mini-Exam of Mental Status (MEMS). All assessments were carried out in the morning, in the “on medication” state, 1 h after participants’ first dose of medication. Inclusion criteria were: independent walker and no cognitive impairment, as judged by the MEMS (according to Brucki et al.’s [19] suggestions for utilization of the MEMS in Brazil). Individuals in the control group had no neurological, musculoskeletal, or cardiorespiratory impairments. Those in the group with PD had been classified into Stages 1–2.5 of the H&Y, did not have other neurological, musculoskeletal, or cardiorespiratory diseases, and were taking regular PD medication.

2.2. Obstacle crossing task

The obstacle crossing task required participants to walk along a pathway (8 m long by 1.4 m wide) and step over an obstacle, under three visual sampling conditions. The obstacle for each condition was positioned in the middle of a pathway, which was covered with a black rubber carpet, 3 mm thick (Fig. 1). Two obstacle heights were selected: low obstacle (ankle height; 5–10 cm), and high obstacle (half-knee height; 20–25 cm). Participants were instructed to walk to the obstacle at their preferred speed, to step over it, and to keep walking until they reached the end of the pathway. Three visual conditions were tested: dynamic (normal lighting), static (static visual samples) and voluntary visual sampling. Three trials in each condition per participant (obstacle × vision = 18 trials) were performed in blocks, according to visual conditions. The presentation order of the conditions was randomized. Trials according to obstacle height also were randomized in each block of visual condition. Subjects wore liquid crystal glasses (Translucent Technologies Plato System, Toronto, Canada) for visual manipulation. These glasses are opaque and eliminate any form of motion information. When an electric current passes through the glasses, they become transparent almost immediately (response time <5 ms), providing subjects with a normal view of the surroundings. Under the static condition, the glasses were controlled by an electronic circuit that provided static visual samples at 3 Hz (sample duration <0.016 s). Under the voluntary visual sampling condition, subjects were allowed to choose when and where to take a visual sample of the environment. They pressed a hand-held switch to make the glasses transparent when they needed to sample the environment.

Participants were instructed to initiate the walking task immediately after the following command: “Ready? Go!”. Visual information related to the environment was not available before the initial command in any experimental condition. Participants were allowed to familiarize themselves with each condition (and the equipment) over three to five unrecorded trials.

2.3. Data analysis

For the kinematic analysis, four passive markers (15 mm diameter reflective, adhesive Styrofoam) were attached to the following anatomic landmarks: (a) 5th right and 1st left metatarsal joints, and (b) lateral face of the right calcaneal and medial face of the left calcaneous. Also, one passive marker was fixed at the obstacle base. Images of the obstacle avoidance task at the center of the pathway were recorded at a frequency of 60 Hz by two digital camcorders (JVC, GR-DVL 9800) [20]. Further details about data processing can be found in earlier studies by our research group.

![Fig. 1. Superior view of the pathway and spatial parameters of obstacle avoidance.](image-url)
The spatial-temporal parameters of obstacle avoidance were (Fig. 1): trailing foot placement before the obstacle, toe clearance (lead and trail), crossing step width, and horizontal mean velocity during obstacle crossing (lead and trail). We also recorded the number of obstacle contacts, through visual inspection. When an obstacle contact occurred, the trial was immediately repeated (only successful trials were considered for data analysis).

Voluntary visual sampling was registered by a light-emitting diode, which was recorded by the camcorders. When the glasses became transparent, the diode illuminated. The following parameters related to visual sampling were obtained: number of samples and total duration of visual samples. Because the people with PD walked slower than the controls, the duration of visual samples, for the total time spent during the walking task, was normalized. Travel time was defined as from the time the “Go!” command was given to the toe-off when the right foot left the floor after the obstacle.

2.4. Statistical analysis

For demographic data, unrelated sample student t-tests were employed for between-group comparisons. For kinematic variables and number of obstacle contacts, three-way ANOVAs (group × visual condition × obstacle height condition) were carried out, with repeated measures in the condition factors. The Bonferroni post hoc test was used to localize the differences among visual conditions (adjusted p-value ≤ 0.017). For voluntary visual sampling variables, two-way ANOVAs (group × obstacle height condition) were performed. The p-value was set at 0.05.

3. Results

The two groups were not significantly different in demographic data. Mean and p values of t-tests for age, body height, and body mass are outlined in Table 1. Clinical data for the individuals with PD are also reported in Table 1.

Table 2 shows dependent variables for each group, in each experimental condition. The post hoc test results for conditions are shown in Table 3. There was no trial effect for all dependent variables.

Interaction between factors (group and visual condition) was observed for obstacle contacts [F(2,4,44) = 3.717, P = 0.027]. The individuals with PD made more obstacle contacts than the controls only in the static visual sampling condition (Fig. 2A).

3.1. Kinematic variables

A trend of interactions between factors (group and visual condition) was observed for crossing step width [F(2,4,44) = 2.897, P = 0.065]. Post hoc tests revealed that the people with PD increased their crossing step width in the static visual condition, while the control group maintained the same values for all visual conditions (Fig. 2B). Interaction between factors was not observed

Table 1

<table>
<thead>
<tr>
<th>Demographic variable</th>
<th>PD</th>
<th>CG</th>
<th>Unrelated sample student t-tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>69.8 ± 5.72</td>
<td>69.6 ± 6.04</td>
<td>t_{12} = 0.104, P = 0.918</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>163.6 ± 7.25</td>
<td>162.1 ± 6.69</td>
<td>t_{22} = 0.243, P = 0.811</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>69.8 ± 10.75</td>
<td>68.8 ± 8.27</td>
<td>t_{22} = 0.498, P = 0.624</td>
</tr>
<tr>
<td>HY (stage)</td>
<td>1.4 ± 0.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDRS-I (score)</td>
<td>3.3 ± 1.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDRS-II (score)</td>
<td>11 ± 4.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPDRS-III (score)</td>
<td>19.8 ± 11.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEMS (score)</td>
<td>27.9 ± 2.91</td>
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</table>
for other kinematic parameters. Univariate analysis for group revealed differences in horizontal mean velocity during obstacle crossing with the leading limb \(F_{(1,22)} = 4.458, P = 0.046\), which were smaller for people with PD. A trend of differences between groups was observed for horizontal mean velocity during obstacle crossing with the trailing limb \(F_{(1,22)} = 3.851, P = 0.062\), which were smaller for people with PD. Univariate analysis for visual condition revealed differences for trailing foot placement before the obstacle \(F_{(2,44)} = 8.377, P = 0.001\), leading toe clearance \(F_{(2,44)} = 25.032, P < 0.001\), crossing step width \(F_{(2,44)} = 8.811, P = 0.001\), and horizontal mean velocity during obstacle crossing with the leading limb \(F_{(2,44)} = 27.687, P < 0.001\), and trailing limb \(F_{(2,44)} = 11.226, P < 0.001\). Both the individuals with PD and the healthy individuals showed earlier trailing foot placement before the obstacle and wider crossing step width in the static than in the dynamic condition. The leading toe clearance values were higher in the static condition than in the dynamic and voluntary visual sampling conditions; values were higher in the voluntary visual sampling condition than in the dynamic condition. Horizontal mean velocities during obstacle crossing (with both limbs) were smaller in the static condition than in the dynamic and voluntary visual sampling conditions. Univariate analysis for obstacle height condition revealed differences for crossing step width \(F_{(1,22)} = 50.929, P < 0.001\), and horizontal mean velocity during obstacle crossing with the leading limb \(F_{(1,22)} = 94.719, P < 0.001\), and the trailing limb \(F_{(1,22)} = 68.918, P < 0.001\). Both the individuals with PD and the healthy individuals showed narrower crossing step width and greater horizontal mean velocities during obstacle crossing (with both limbs) in the low obstacle height versus the high obstacle height condition.

### 3.2. Voluntary visual sampling variables

Interaction between factors (group and obstacle height condition) was not observed for the voluntary visual sampling variables. Univariate analysis for group revealed differences for number of samples \(F_{(1,22)} = 7.066, P = 0.014\), which was greater for healthy individuals. Univariate analysis for obstacle height condition revealed differences for number of samples \(F_{(1,22)} = 7.333, P = 0.013\). Both the individuals with PD and the healthy individuals showed a greater number of samples in the high obstacle than in the low obstacle condition.

### 4. Discussion

The current study addressed the role of visual information on gait control in people with PD and in healthy individuals as they crossed over obstacles of different heights. Between groups, differences in crossing step width and number of obstacle contacts were observed only under the static visual condition; the individuals with PD registered greater values than did the control group. These findings suggest that, for the patients with PD, visual control during the crossing of obstacles were different than that observed in the healthy, age-matched controls. Optic flow information, even for intermittent periods (voluntary visual sampling condition), was demonstrated to be relevant to the individuals with PD with regard to task success and postural stability, which were assessed via number of obstacle contacts and crossing step width, respectively. In a previous level-ground walking study with the same visual conditions, Vitório et al. [14] demonstrated that the visual control of gait by patients with PD was similar to that observed in healthy, age-matched controls. The results of both studies suggest that, in individuals with PD, environmental constraints such as postural threat elicited the dependence of locomotion on dynamic visual information. Thus, task complexity is an important issue to be considered while evaluating locomotion control in PD patients, mainly in those that are mildly affected.

Although bradykinesia may have influenced the characteristics of voluntary visual sampling in the individuals with PD (healthy

![Fig. 2](image-url) Interaction between group and visual condition for (A) total number of obstacle contacts and (B) crossing step width.
controls showed a greater number of samples than did the patients with PD, there were no significant differences between groups for the total duration of visual samples. While crossing the obstacle in the voluntary visual sampling condition, the individuals with PD required the same amount of visual information as did the control subjects to guarantee task success and postural stability. The crucial factor seems to be the kind rather than the amount of visual information used in locomotion control. The patients might have processed static visual information inappropriately, leading them to have an incorrect perception of limb self-motion in relation to the obstacle. Optic flow information is used to determine time to contact [9]. In addition, proper visual information processing is crucial for the planning and controlling of adaptive gait [12,13]. Thus, deficits in visual information processing could be the major cause of an elevated number of obstacle contacts in the patients with PD in the static visual sampling condition. Due to well-documented proprioceptive deficits [15,16], patients with PD rely more on visual cues for locomotion control; optic flow seems to be critical in determining task success and postural stability only when an obstacle has been added to the travel path.

It is possible that the individuals with PD used the obstacle as an external cue to regulate an adaptive gait [6]. However, this strategy was not effective when optic flow was suppressed. It appears that dynamic visual information is necessary in order for an obstacle to become an external visual cue, therefore guaranteeing task success for the patients with PD. However, this finding should be interpreted carefully, since visual control during obstacle crossing did not differ between groups for other relevant spatial parameters (i.e., foot placement before the obstacle, and toe clearance) during successful trials. Thus, we still cannot confirm that optic flow is the mechanism through which external visual cues help improve locomotor behavior in those with PD [10].

Regardless of the visual and obstacle height conditions, the individuals with PD crossed the obstacle slower than did their matched control counterparts. Similar to previous studies [67,6], leading and trailing toe clearance did not differ between groups. Also, foot placement before the obstacle was not different between groups. It can be argued that bradykinesia affected the crossing of the obstacle in patients with PD, and that the obstacle was used as an external visual cue to modulate toe clearance. It was an effective strategy to compensate for the hypometric behavior we observed during level-ground walking in our previous study with the same subjects [14].

The set of modulations in the obstacle avoidance parameters, as revealed by the main effect of obstacle height and visual condition, suggests that both the individuals with PD and the control subjects demonstrated a more conservative strategy (i.e., higher leading toe clearance and smaller horizontal mean velocities during obstacle crossing) during the half-knee-height and static visual sampling conditions. Since crossing step width increased under these conditions, it seems possible that a higher limb elevation over the obstacle was a challenge to postural stability.

Trailing toe clearance did not change across visual conditions, suggesting that this parameter is not controlled by visual information. All of the other avoidance parameters analyzed in the current study were shown to be dependent on optic flow information, and were modulated as a compensatory strategy. In the voluntary visual sampling condition, all of the spatial-temporal parameters of obstacle crossing – except leading toe clearance – showed similar values to those observed in the dynamic visual sampling condition. These findings suggest that, in individuals with mild to moderate PD and their healthy age-matched controls, the regulation of leading toe clearance is dependent on continuous dynamic visual sampling.

In conclusion, the locomotor behavior of both groups was influenced by obstacle height and available visual sample. The individuals with PD were more dependent on dynamic visual information for postural stability and for successful performance of the proposed task than were the control subjects. Bradykinesia influenced obstacle crossing in the individuals with PD. Leading toe clearance regulation is dependent on continuous optic flow information. The current findings represent a step forward in the understanding of how people with PD use visual information for locomotion control.

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Conflict of interest statement

The authors have no conflicts of interest to disclose. All authors disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) our work and manuscript. All authors have approved the final article.

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