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Research report

Synchrony of gaze and stepping patterns in people with Parkinson's disease

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HIGHLIGHTS

- We studied the synchronism of gaze and stepping patterns in Parkinson's disease.
- Participants walked through paths with foot placement targets (one vs. two targets).
- Patients and healthy participants prioritized the planning of future actions.
- Only patients increased A-P foot placement error in the Two Target condition.
- Patients are dependent on on-line visual information to guarantee an accurate step.

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ABSTRACT

The aim of the present study was to test the hypothesis that people with Parkinson's disease (PD) are more dependent than healthy individuals on visual information in an on-line manner to guarantee accurate foot placement into an intended stepping target. Patients with PD and age-matched healthy participants walked along a pathway and were required to step onto either one or two targets during the walk trial. Outcome measures included absolute error (accuracy) and error variability (precision) of foot placement onto the first target, and the time interval between the gaze transfer away from the first target and heel contact on the same target. When there was a single target in the travel path, both groups fixated the target until after heel contact on the target. However, when challenged with an additional target, both groups transferred their gaze from the first target prior to heel contact. Interestingly, only people with PD increased anterior-posterior absolute error (first target) when there was more than one target in the travel path. Premature gaze transfer was associated with decline in stepping accuracy (anterior-posterior absolute error) in people with PD. These findings suggest that both people with PD and healthy individuals prioritize the planning of future actions over the execution of ongoing steps, while walking. Additionally, current findings support the notion people with PD are more dependent on visual feedback to make on-line corrections and adjustments to their foot trajectory in order to guarantee accurate foot placement into an intended stepping target.

1. Introduction

It is well documented that people with Parkinson's disease (PD) fall more frequently than healthy individuals [1,2]. Most falls occur during gait in PD and therefore previous research has focused on identifying disease-related deficits in locomotor performance that lead to falls. Several studies have reported foot clearance difficulties during obstacle crossing by people with PD [3–6]. Not surprisingly, tripping over obstacles has been identified as one of the major causes of falls in PD [7]. Since walking over obstacles requires

Abbreviations: PD, Parkinson's disease; MMSE, Mini Mental State Examination; UPDRS, Unified Parkinson's Disease Rating Scale; IRED, infrared light-emitting diode; ANOVA, analysis of variance.

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visually guided foot placement on specific locations, deficits in sampling and/or processing visual information from the environment might be an important cause of tripping. Importantly, people with PD report basic visual deficits such as impaired visuo-perceptual function and reduced contrast sensitivity [8,9]. In addition, eye-tracking studies have demonstrated visual sampling impairment in people with PD, such as hypometric voluntary sampling and variable reflexive saccades [10–12]. Most of these previous studies involve sitting in front of a computer, and hence fail to take into consideration how visual impairments may be compounded by movement itself. Then, it is important to investigate disease-related visual sampling deficits during walking in people with PD [13].

Walking safely through cluttered environments requires visual identification of obstacles and safe places to step. It is well established that there are strong spatiotemporal relationships between eye and stepping movements during precision walking tasks. For example, gaze stabilization with respect to footfall targets plays a crucial role in the control of visually guided stepping (e.g. obstacle avoidance or foot placement on targets) [14,15]. Previously, Chapman and Hollands [14] demonstrated that, when there was more than one stepping constraint in the travel path, in contrast to young and low-risk older adults, older adults categorized as having a high-risk of falling transferred gaze away from the first target prior to completing the step on that same target, in order to fixate on an upcoming target. This early transfer of gaze by high-risk older adults was accompanied by an increase in foot placement variability in the first target. Authors proposed that older adults who are prone to fall may prioritize the planning of future actions over the accurate execution of ongoing movements, which may contribute to an increased likelihood of falls.

To our knowledge, the synchrony between gaze and stepping patterns during walking in people with PD has only been investigated in one study. A recent study from our group [16] demonstrated that both people with PD and healthy individuals use similar gaze behavior to capture visual information from visual cues while walking on a cued pathway with targets for each step (participants were instructed to touch each line with their heels consecutively as they proceed through the trial). Both groups employed equal distribution of on-line (use of visual information available during ongoing step) and feedforward (use of visual information that was viewed ahead of the currently occurring step; to plan ahead) visual control of gait, but people with PD performed less accurate foot placements on the target cues when they employed the feedforward visual control [16]. It is important to note that the use of feedforward control while stepping on specific targets requires relatively intact proprioception (to guide the concurrent steps without visual information of the foot relative to the target, as vision is directed ahead) and storage capacity in the working memory (to remember target position) to guarantee accurate foot placements. The results of our previous study [16] suggest that people with PD may be more dependent on the availability of visual information in an on-line mode to fine tune the accuracy of foot placement on targets; probably to compensate the proprioceptive and working memory deficits usually observed in people with PD [17–19]. However, stepping accuracy was not stressed in the instruction offered to participants in our previous study [16], making it difficult to solidly support this conclusion. As such, it is necessary to study gaze and locomotor behavior of people with PD while performing a task which requires accurate foot placements on desired locations.

In the current study, people with PD and healthy individuals were required to walk through two different travel paths with foot placement targets (one vs. two targets) while wearing a head mounted gaze tracker unit. By manipulating foot placement pattern (travel path with foot placement targets) and monitoring gaze and stepping behavior, it was possible to determine how people with PD and healthy individuals synchronized gaze and stepping patterns during the target-directed gait. The aim of the present study was to test the hypothesis that people with PD are more dependent than healthy individuals on visual information in an on-line manner to guarantee accurate foot placement into an intended stepping target. Since people with PD fall frequently and they demonstrate proprioceptive and working memory deficits, we expected to observe increased foot placement error when patients with PD use feedforward control (early gaze deviation from the target to be stepped).

2. Material and methods

2.1. Participants

This study adhered to the guidelines of the Declaration of Helsinki, and it was approved by the Research Ethics Board at Wilfrid Laurier University. All participants signed a consent form before participating in the experimental protocol. Twenty four patients with PD (12 males) and 18 age-matched control subjects (8 males) were recruited from a database at the Sun Life Financial Movement Disorders Research and Rehabilitation Centre at Wilfrid Laurier University in Waterloo, Ontario, Canada. Patients were selected on the criteria of having confirmed PD diagnosis from at least one neurologist. A movement disorder specialist performed a clinical assessment in order to test patients on the Unified Parkinson's Disease Rating Scale (UPDRS, [20]), the Hoehn and Yahr Rating Scale (H&Y, [21]) and the Mini Mental State Examination (MMSE, [22]). Patients were tested in the ON state of medication (approximately 1 h after having taken a dose). The levodopa equivalent daily dose was calculated according to Tomlinson's suggestions [23]. Patients with PD who experienced freezing of gait were excluded from the study. Participants in both groups had no other neurological, musculoskeletal or cardiorespiratory disturbances that could impair walking ability. All participants were cognitively preserved (scored at least 27 on the MMSE).

2.2. Protocol and data analysis

Participants were required to walk along a pathway 8 m long, at a self-selected pace, and step on one of two target conditions (Fig. 1). The "One target" condition required participants to place their right foot onto target 1. The "Two target" condition required participants to place their right foot onto target 1 and then subsequently their left foot onto target 2. Participants were instructed to place each foot accurately in the central area of the targets. Five trials in each condition per participant (10 trials) were performed in a random order. The targets were rectangular and made of lightweight foam rubber measuring 19 cm × 41.5 cm [14]. The targets were positioned at the central area of the pathway at constant distance apart (A-P separation = 180 cm, M-L separation = 45 cm). Prior to the start of each trial, participants were instructed to close their eyes. Each trial began on a verbal signal "Ready? Go!", at which point participants were instructed to open their eyes and start the experimental task.

Foot 3-D kinematic data were collected using an Optotrak wireless system (Northern Digital Inc., Waterloo, Ontario, Canada) with five position sensor cameras (one placed on the wall at the end of the pathway, two placed on the right and two placed on left side of the pathway). A total of six infrared light-emitting diodes (IREDs) were attached bilaterally to the following anatomic landmarks: (a) first metatarsal and fifth metatarsal heads and (b) back of the calcaneous. These IREDs were tracked at a sampling frequency of 120 Hz. The following gait variables were calculated for the step ending in