Neuroscience 274 (2014) 162–169

A CLOSER LOOK AT MECHANISMS UNDERLYING PERCEPTUAL DIFFERENCES IN PARKINSON'S FREEZERS AND NON-FREEZERS

K. A. EHGOETZ MARTENS, [a,b] **C. G. ELLARD** [b] **AND Q. J. ALMEIDA** [a]*

[a] *Sun Life Financial Movement Disorders Research and Rehabilitation Centre, Wilfrid Laurier University, 75 University Avenue West, Waterloo, Ontario N2L 3C5, Canada*

[b] *Department of Psychology, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada*

Abstract—Parkinson's disease patients who suffer from freezing of gait (PD-FOG) may have sensory and/or perceptual deficits, although they are difficult to disentangle. This study evaluated whether visuospatial perception or self-motion perception were more impaired in PD-FOG, and whether distance estimation errors might be related to misperception of physical walking (compared to imagined). Finally, cognitive status was evaluated in order to evaluate whether cognitive status predicts any of the perception deficits identified. Nine PD-FOG and 15 PD-nonFOG were tested. In experiment 1, participants were shown a target, then the target was removed, before participants demonstrated the original position of the target in two different feedback conditions (pointing with a laser, or walking to its original position). In experiment 2, participants walked to a target (3, 4.5, 6 m) and then imagined walking to that same target. The time to complete both of these tasks was measured and compared. Experiment 1 found a significantly greater judgment error in PD-FOG across both conditions ($p = 0.013$) (compared to PD-nonFOG). Constant error revealed that both groups significantly underestimated during the self-motion condition only ($p = 0.01$). Interestingly, results from experiment 2 demonstrated a significant discrepancy between the time it took to imagine walking compared to their actual movement times, specifically in PD-FOG ($p = 0.03$). This mismatch as well as cognitive status significantly predicted judgment errors during the self-motion condition from experiment 1. Therefore, this study found evidence that PD-FOG have significantly greater sensory–perception deficits compared to PD-nonFOG. These findings have important clinical implications for further understanding FOG and developing new rehabilitative strategies for FOG symptoms.

Key words: Parkinson's disease, freezing of gait, perception, sensory feedback, motor imagery.

INTRODUCTION

Freezing of gait (FOG) is a severe symptom of Parkinson's disease (PD) where the patient is transiently unable to produce a forward step. Almeida and Lebold (2010) suggested that FOG might be a result of an underlying sensory–perceptual impairment interfering with online movement planning (Almeida and Lebold, 2010), since spatio-temporal aspects of gait worsened specifically when the freezers approached a narrow doorway. Accurate perception of both the environment and self-motion are essential in order to properly navigate and negotiate obstacles (such as doorways). A deficit affecting either of these processes might impair movement planning and could potentially contribute to FOG. Therefore, it is important to investigate whether PD-FOG demonstrate impaired perception of their environment (i.e. visuospatial deficit), or a separate self-motion deficit, compared to PD-nonFOG.

To address whether PD-FOG misperceive the width of a doorway, Cohen and colleagues had participants judge whether or not they could pass through different-sized doorways (Cohen et al., 2011), although they did not find differences between PD-FOG and PD-nonFOG. Thus, concluding no impairments in perception of the environment. In contrast, Nantel and colleagues showed with correlational analyses that visuospatial deficits in PD-FOG were negatively related to both the FOG-q and FOG stepping in place metrics (Nantel et al., 2012), suggesting that PD-FOG may have impaired visuospatial processing of their environment. Although Cohen and colleagues did not find differences in judgments between PD-FOG and PD-nonFOG, perhaps estimating one's shoulder width relative to a doorway does not give a true sense of whether PD-FOG accurately perceive the doorway width. Furthermore, while correlations between FOG and visuospatial deficits are suggestive of an underlying mechanism, a direct comparison is needed to evaluate whether PD-FOG misperceive their environment.

An important alternative to consider when trying to understand doorway freezing is whether individuals with FOG may be impaired in perception of self-motion, making it difficult for them to accurately update the progression of their movement online. Distance estimation deficits have recently been found to be amplified during movement in those with PD possibly as a consequence of impaired proprioceptive processing or visual–proprioceptive integration (Almeida et al., 2005;

*Corresponding author. Tel: +1-519-884-1970x3924; fax: +1-519-747-4594.
E-mail address: qalmeida@wlu.ca (Q. J. Almeida).
Abbreviations: ANOVA, analysis of variance; FOG, freezing of gait; PD, Parkinson's disease; UPDRS, Unified Parkinson's Disease Rating Scale.

http://dx.doi.org/10.1016/j.neuroscience.2014.05.022
0306-4522/

Ehgoetz Martens et al., 2013a). Furthermore, greater amounts of FOG were also reported in PD-FOG specifically when patients had to rely most heavily on proprioceptive feedback (i.e. walk toward a doorframe in the dark) compared to when vision of the door or their body was available (Ehgoetz Martens et al., 2013b). Thus, PD-FOG may also have sensory processing impairments; however the relative severity of such deficits in patients who experience FOG compared to PD-nonFOG remains unknown.

The first aim of the current study was to formally quantify perceptual deficits in PD-FOG compared to PD-nonFOG. Experiment 1 evaluated: (i) whether visuospatial perception of the environment (i.e. static) and/or (ii) self-motion perception (i.e. while walking) were impaired in PD-FOG compared to PD-nonFOG. Based on the suggestion that visuospatial impairments (Nantel et al., 2012) contribute to FOG, it was hypothesized that PD-FOG would demonstrate greater judgment error compared to PD-nonFOG when required to point to the position of the remembered target (i.e. during the static visuospatial perception task). Additionally, it was hypothesized that PD-FOG would also demonstrate greater judgment error than PD-nonFOG, which may be amplified during the self-motion perception task. This is in accordance with previous research suggesting sensory processing impairments in PD-FOG during self-motion tracking (Ehgoetz Martens et al., 2013b).

Interestingly, a recent study found a mismatch between imagined and actual movement times, specifically in PD-FOG while walking through a narrow doorway (Cohen et al., 2011). Although Freezers misrepresented their imagined pace significantly, it is important to note that the groups were not matched for symptom severity. In fact, the PD-FOG were significantly more severe than the PD-nonFOG. Given that movement time was self-measured by the patients, and motor severity was different between groups, it is important to interpret these findings carefully. Nonetheless, a mismatch between imagined and actual movement time in PD-FOG might be further evidence of a sensorimotor integration deficit, however this relationship remains speculative.

Therefore, experiment 2 aimed to investigate whether PD-FOG misperceive actual movement compared to imagined movement (as suggested by Cohen et al., 2011), and furthermore whether this misperception might predict distance estimation error from experiment 1. In the current study we purposefully avoided evaluating responses to doorways, so that we might ascertain movement times unaffected by freezing of gait behavior. Thus, the current experiment evaluated PD-FOG and PD-nonFOG in an open hallway to avoid any potential triggers to FOG that might affect time-to-completion. Since symptom severity was significantly different between groups in the previous study (Cohen et al., 2011), we also investigated whether there was a relationship between symptom severity and perceptual judgment error, in order to confidently identify whether perceptual deficits were unique to PD-FOG or simply a result of disease progression.

EXPERIMENTAL PROCEDURES

Subjects

Nine participants who were confirmed to experience FOG a specific and stringent clinical assessment criteria (Almeida and Lebold, 2010; Knobl et al., 2012) were tested. Seventeen participants who did not meet the clinical assessment criteria for FOG were also tested. In order to rule out that findings of the current study could be explained by disease severity or cognitive status, only 15 PD non-freezing participants were included in the analysis (see demographic Table 1). All participants were recruited from the patient database at the Sun Life Financial Movement Disorders Research and Rehabilitation Centre at Wilfrid Laurier University and were tested in their ON-state. Exclusion criteria included: visual disturbances impairing distance acuity (> 20/50 on the Snellen Eye Chart), poor contrast sensitivity (< 18/42 score on the Peli-Robson chart), gait impairments preventing individuals from walking 10 m unassisted, impaired cognitive status (< 70/100 score on the Modified Mini Mental State Exam – 3MS), or spatial working memory impairments (< level 3 on the Corsi block tapping task). Ethical approval was obtained by both the REB at Wilfrid Laurier University as well as the ORE at the University of Waterloo. Informed consent was obtained from all participants before participating.

Apparatus

Participants completed judgment trials in a clutter free large laboratory with free standing white walls at the edge of the room, preventing additional visual cues in the environment. A 7-m white runner carpet was placed on the floor in front of the participants start position length-wise. This carpet was used to prevent the floor pattern from interfering or aiding individuals' judgments of distance and increased the contrast between the floor and the black target box. Three infrared light emitting diodes (IRED) were fastened securely to the rear facing side of the black target box and were used to calculate absolute, constant and variable error measures. Two OPTOTRAK cameras were placed at the end of the room, 1 m from the end of the carpet in order to capture target's position.

Procedure

Experiment 1: perceptual judgment. To evaluate perceptual judgment, participants completed 24 estimates of distance (ranging from 2.5 to 7 m in random order) in two randomized blocks of condition: 12 trials of static visuospatial judgments and 12 trials of self-motion (walking) judgments. Each condition of 12 trials comprised of three short trials (average distance 2.5 m, SD = 0.6), three medium length trials (average distance 3.9 m, SD = 0.5), three intermediate distance trials (average distance 4.8 m, SD = 0.5) and three long distance trials (average distance 5.5 m, SD = 0.4). Therefore, each participant received an equal number of the short, medium, intermediate and long trials, even