Parkinsonism and Related Disorders 22 (2016) 42–47

Contents lists available at ScienceDirect

Parkinsonism and Related Disorders

journal homepage: www.elsevier.com/locate/parkreldis

Smartphone-based tactile cueing improves motor performance in Parkinson's disease

Vladimir Ivkovic [a, *, 1], Stanley Fisher [a, b, 2], William H. Paloski [a]

[a] University of Houston, Center for Neuromotor and Biomechanics Research at The National Center for Human Performance, 2450 Holcombe Boulevard, Houston, TX 77021, USA
[b] Movement Disorders and Neurorehabilitation Center, Methodist Neurological Institute, 6560 Fannin Street, Suite 802, Houston, TX 77030, USA

A R T I C L E I N F O

Article history:
Received 15 August 2015
Received in revised form
19 October 2015
Accepted 1 November 2015

Keywords:
Smartphone
Tactile
Cueing
Movement
Parkinson's

A B S T R A C T

Introduction: Visual and auditory cueing improve functional performance in Parkinson's disease (PD) patients. However, audiovisual processing shares many cognitive resources used for attention-dependent tasks such as communication, spatial orientation, and balance. Conversely, tactile cues (TC) may be processed faster, with minimal attentional demand, and may be more efficient means for modulating motor-cognitive performance. In this study we aimed to investigate the efficacy and limitations of TC for modulating simple (heel tapping) and more complex (walking) motor tasks (1) over a range of cueing intervals, (2) with/without a secondary motor task (holding tray with cups of water).
Methods: Ten PD patients (71 ± 9 years) and 10 healthy controls (69 ± 7 years) participated in the study. TCs was delivered through a smart phone attached to subjects' dominant arm and were controlled by a custom-developed Android application.
Results: PD patients and healthy controls were able to use TC to modulate heel tapping ($F(3.8,1866.1) = 1008.1$, $p < 0.001$), and partially modulate walking ($F(3.5,1448.7) = 187.5$, $p < 0.001$) tasks. In the walking task, PD patients modulated performance over a narrower range of cueing intervals ($R^2 = 0.56$) than healthy controls ($R^2 = 0.84$; group difference $F(3.5,1448.7) = 8.6$, $p < 0.001$). TC diminished synchronization error associated with performance of secondary motor task during walking in PD patients and healthy controls (main effect of Task ($F(1,494) = 0.4$; $p = 0.527$), Task X Group interaction ($F(1,494) = 0.5$; $p = 0.493$)).
Conclusion: This study expands modalities of TC usage for movement modulation and motor-cognitive integration in PD patients. The smartphone TC application was validated as a user-friendly movement modulation aid.

1. Introduction

Current models of Parkinson's disease (PD) neuropathology [1] suggest that reduced dopamine availability to basal ganglia (BG) causes dysfunctional posterior BG output. Since posterior BG mediate timing of motor activity [2,3], decreased dopamine availability results in decreased motor automaticity and increased reliance on executive control for motor-cognitive performance [4,5]. This results in slower attention shifting, longer processing times, and contributes to increased risk of falling.

Martin [6] pioneered research on sensory cueing for movement modulation in BG disorders by demonstrating the efficacy of visual cueing for improving gait. The utility of sensory cues as motor modulators is believed to stem from their processing through afferent cerebello-nigro-thalamo-cortical pathways which remain

List of abbreviations: BG, Basal Ganglia; BMI, Body Mass Index; CSI, Comfortable Stepping Interval; H–Y, Hoehn–Yahr (scale/score); ISI, Inter Step Interval; ITI, Inter Tap Interval; MMSE, Mini Mental State Exam; PAR-Q, Physical Activity Readiness Questionnaire; PD, Parkinson's disease; SPSS, Software Package used for Statistical Analyses; SRPA-Q, Self-Reported Physical Activity Questionnaire; TC, Tactile Cueing; TCI, Tactile Cueing Interval; UH, University of Houston; UPDRS, Unified Parkinson's Disease Rating Scale.

* Corresponding author.
E-mail addresses: vivkovic@nmr.mgh.harvard.edu (V. Ivkovic), stafisher@saint-lukes.org (S. Fisher), whpalosk@central.uh.edu (W.H. Paloski).
[1] Present address: Harvard Medical School/Massachusetts General Hospital, Department of Psychiatry, Neural Systems Group; 149 13th Street, Rm 2651, Charlestown, MA 02129, USA.
[2] Present address: Saint Luke's Marion Bloch Neuroscience Institute, 4401 Wornall Road, Suite 1708, Kansas City, MO 64111, USA.

http://dx.doi.org/10.1016/j.parkreldis.2015.11.006
1353-8020/

mostly preserved in PD [1,7]. Visual and auditory cueing have been shown to ameliorate balance and gait related symptoms and improve motor learning in PD patients [8–11].

Comparatively, tactile inputs may override the otherwise dominant visual proprioceptive inputs [12] and may be processed subconsciously [13] faster than the visual inputs [14]. Application of tactile cueing (TC) could therefore be a feasible modality for improving motor control in PD patients that also reduces the burden on their executive control.

While results of studies investigating TC [8,11,15–17] have been promising, no randomized controlled trials that investigated TC efficacy in modulating simple (e.g. seated heel tapping) and more complex (e.g. walking) motor tasks have been reported. Unlike seated heel tapping, gait is subject to additional neuromotor constraints including control of balance, coordination, and dynamic spatial orientation [18] all of which make walking a more complex activity. The lack of studies investigating the efficacy and limitations of TC on modulating motor-cognitive integration in PD over a range of activities prevents exploitation of its potential as movement modulation aid.

Thus, we examined movement modulation efficacy of TC over a range of activities in moderately impaired PD patients and healthy individuals, who performed seated heel tapping and straight line walking tasks with and without a secondary motor task – holding a tray with two cups of water (as reported by Rochester et al. [19,20]). For each combination of tasks we evaluated performance associated with two cueing frequencies that bracketed the individual's comfortable stepping frequency. We hypothesized that (1) PD patients would modulate heel tapping and straight line walking cadences to TC over a range of cueing intervals; (2) increased task complexity would limit the range of TC intervals over which PD patients could modulate performance; (3) TC would improve PD patients' performance in the presence of a secondary motor task.

2. Materials and methods

2.1. Subjects

Participating patients were diagnosed with idiopathic Parkinson's disease by a neurologist member of the investigator team, and were on stable regimen of one of the following anti-Parkinsonian medications: (Azilect (rasagiline), Mirapex (pramipexole), Sinemet (carbidopa/levodopa), Stalevo (carbidopa/levodopa-entacapone). They were able to walk independently and follow multistep directions. Healthy participants were recruited from the general population, and were sex-, age- (±2 years), and activity-level-matched to the patients. The study was conducted in compliance with the Declaration of Helsinki, the Federal and University of Houston (UH) policies regulating conduct with, and protection of human subjects in research. The study protocol was approved by the UH Committees for the Protection of Human Subjects. Each participant provided written, informed consent prior to participating. Age range for inclusion in this study was 55–85 years.

All participants were free of significant medical conditions and cognitive impairments that could have affected participation in the study, which was ascertained by the modified Physical Activity Readiness Questionnaire (PAR-Q) [21], and a score of 27 or higher on the Mini-Mental State Examination (MMSE) [22]. Included in the study were minimally or moderately physically active individuals (0–3 score on the Self-Reported Physical Activity Questionnaire (SRPA-Q) [23]. Only moderately impaired PD patients (stage 2–4 on the Hoehn-Yahr motor disability scale [24]) were included in the study. Individuals with history of freezing of gait, brain surgery or placement of a deep brain stimulator for PD, history of head trauma that resulted in loss of consciousness 6 months prior to participation, previous exposure to sensory cueing, or cognitive impairment, were excluded from the study.

2.2. Apparatus

Tactile cues were administered using a 0.16 kg smartphone (MyTouch-3G™ HTC, Bellevue, Washington) affixed to the lateral aspect of the less affected upper arm in contact with humero-radial joint by a Velcro strap. TCs were provided using the embedded vibrator oscillating at 100 Hz, consisted of 100 ms vibration pulses at the desired tactile cueing intervals TCIs. TCIs for each participant were determined from the participant's average comfortable step interval (CSI) calculated while walking over ground at their comfortable pace [25]. To evaluate the effects of TCI on performance, two shorter TCIs (CSI−55 ms, CSI−125 ms), and two longer TCIs (CSI+55 ms, CSI+125 ms) were computed from the CSI for each participant (Table 1). The ±55 ms and ±125 ms intervals corresponded to ±10% and ±20% from comfortable stepping intervals reported in analogous auditory cueing studies, wherein synchronized gait performance was found to break down at ±20% from comfortable [15,26–28].

Motor performance was assessed from kinematic data collected using three triaxial inertial orientation trackers (Model MTx, Xsens Technologies B.V., Netherlands) attached near the subject's center of mass (midline, above the sacrum) and on the lateral aspects of subject's left and right thighs midway between the hip and the knee. A fourth sensor was attached to the smartphone to record TC vibrations and serve as an event marker during cued trials. The MTx sensors were connected to a portable data logger (Xbus Master B, Xsens Technologies B.V., Netherlands) which digitized MTx sensors data at 100 Hz. A GAITRite instrumented walkway (Model #4.7.0, CIR Systems Inc., Peekskill, NY) was used to determine baseline gait parameters.

2.3. Procedures

PD patients took the prescribed medication upon arrival at the test facility. During the next 45 min their anthropometric measures were recorded, they were fitted with inertial sensors and TC smartphone, and they rehearsed tapping their foot in cadence with TC. After 45 min the “on medication” state was verified by self-report, and examination of items 3.1–3.10 of the Unified Parkinson's Disease Rating Scale (UPDRS; as described by Nieuwboer et al. [29]); the same procedure was repeated to ensure the “on medication” state in the middle of the protocol, and after its completion. The MMSE was then administered to assess cognitive function. The healthy controls followed the same protocol, but without taking medication.

Baseline gait parameters were established in three walking trials at the participants' comfortable walking speed over a straight 15 m walkway with the 5 m long GAITRite pressure mat located in the middle of it. Step interval, step length, cadence, and gait speed were calculated immediately by GAITRite. The CSI was calculated as the average of the step intervals over the three baseline walking trials at comfortable speed. The same parameters were calculated off-line from the Xsens data for quality control and calibration.

The aim of Experiment 1 was to investigate the ability of PD patients and healthy controls to modulate simple heel tapping in response to TC. The participants were seated in a chair with feet on the ground, knees bent at ≈90°, and back straight leaning against the back rest. The arm to which the smart phone was attached rested comfortably on a padded table surface to minimize motion and/or discomfort. During dual-task trials both arms were used to stabilize a tray holding two cups of water. The participants were required to tap the heel of their preferred leg (while keeping their