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Altered kinematics of arm swing in Parkinson's disease patients indicates declines in gait under dual-task conditions

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ABSTRACT

Objective: Declines in simultaneous performance of a cognitive and motor task are present in Parkinson's disease due to compromised basal ganglia function related to information processing. The aim of this project was to determine if biomechanical measures of arm swing could be used as a marker of gait function under dual-task conditions in Parkinson's disease patients.

Methods: Twenty-three patients with Parkinson's disease completed single and dual-task cognitive-motor tests while walking on a treadmill at a self-selected rate. Multiple cognitive domains were evaluated with five cognitive tests. Cognitive tests were completed in isolation (single-task) and simultaneously with gait (dual-task). Upper extremity biomechanical data were gathered using the Motek CAREN system. Primary outcomes characterizing arm swing were: path length, normalized jerk, coefficient of variation of arm swing time, and cognitive performance.

Results: Performance on the cognitive tasks were similar across single and dual-task conditions. However, biomechanical measures exhibited significant changes between single and dual-task conditions, with the greatest changes occurring in the most challenging conditions. Arm swing path length decreased significantly from single to dual-task, with the greatest decrease of 21.16%. Jerk, characterizing smoothness, increased significantly when moving from single to dual-task conditions.

Conclusion: The simultaneous performance of a cognitive and gait task resulted in decrements in arm swing while cognitive performance was maintained. Arm swing outcomes provide a sensitive measure of declines in gait function in Parkinson's disease under dual-task conditions. The quantification of arm swing is a feasible approach to identifying and evaluating gait related declines under dual-task conditions.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder resulting from loss of dopaminergic cells in the substantia nigra. Diminished dopamine reduces effectiveness of the basal ganglia-thalamocortical circuits, resulting in loss of motor, associative/cognitive, and limbic functions. Typical disease manifestation resulting from circuit disruption is marked by four cardinal physical symptoms - resting tremor, bradykinesia, rigidity and postural instability. Typically observed gait-related changes include stooped posture, shuffling gait, reduced arm swing, reduced stride-length and decreased joint range of motion [1]. Of these markers of gait dysfunction, decreased arm swing is most commonly reported [1].

Parkinson's disease related changes in arm swing include decreased range of motion, decreased acceleration, and increased asymmetry between limbs [2,3] during gait. In healthy individuals, the reciprocal control of arm swing and leg movements during walking is neurally coupled, and likely controlled by central pattern generators [4]. The successful performance of gait is characterized by the integration of both spinal cord output and higher level executive processes [4]. Parkinson's disease disrupts these neural circuits [5], resulting in gait impairments; however, it is not well understood how the executive control processes in conjunction

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with central pattern generator circuits are affected. Previous studies have provided insight on possible mechanisms for arm swing decline in PD gait, such as the sub-thalamic nucleus preferentially activating the lower extremities over the upper [6], and have been shown to worsen with increasing cognitive demands (i.e. dual-task (DT)) [7].

Dual-task paradigms provide a method to evaluate and manipulate the process of allocating executive function resources and their overall capacity. During cognitive-motor DT activities, increases in attentional demands necessitate greater utilization of executive function to manage the increased cognitive load. Predictably, increased task complexity reflects increased prefrontal cortical activity [4,8]. The allocation of additional resources to a difficult cognitive task disrupts normal gait function in older adults and PD patients [8]. Healthy older adults exhibit significant decreases in DT gait performance, characterized by changes in step velocity, step time, step length [9] and increased arm swing asymmetry [10]. Individuals with PD generally exhibit even greater DT costs (DTC) than healthy peers, including decreases in joint range of motion, step length and width, and cadence, as well as increases in asymmetry and variability [9,11–13].

Gait related declines in PD defined by lower extremity measures are well characterized [9,11–13]. However, these measures can be difficult to acquire and process. Understanding DT declines associated with PD using arm swing is not well established, especially under various conditions requiring different types of cognitive processing.

It was hypothesized that cognitive loads accessing different cognitive domains of variable difficulty would elicit declines in arm swing motion in people with PD under DT conditions. It was predicted that path length, normalized jerk and coefficient of variation of arm swing time (cvAST) would be appropriate metrics to accurately quantify changes in quality of movement relating to cognitive resource allocation.

2. Methods

2.1. Study design

A prospective research study was conducted investigating the effects of single-task (ST) and DT cognitive-motor interventions on changes in cognitive function and gait. All participants completed the informed consent process approved by the Institutional Review Board of Cleveland prior to data collection.

2.2. Participants

Twenty-four participants were recruited from the Cleveland Clinic Center for Neurological Restoration; one participant was unable to complete cognitive testing and was excluded from analysis. The remaining 23 participants were included in analysis. Inclusion criteria were as follows: adults with idiopathic PD, Hoehn and Yahr stage 2–4, able to ambulate >300 feet with or without use of an assistive device. Exclusion criteria included: deep brain stimulation or other PD-specific surgical intervention, musculoskeletal injury or neurological disease other than PD that would restrict ambulation, inability to follow two-step commands, and three or more errors on the Short Portable Mental Status Questionnaire [14]. All participants were tested one hour after taking their anti-Parkinsonian medications to ensure testing during “on” state. No participant used an assistive device.

2.3. Equipment

Biomechanical data were gathered using the Computer Assisted Rehabilitation Environment (CAREN) system (MotekforceLink, Amsterdam, Netherlands) located on the Cleveland Clinic's main campus. The CAREN system is an integrative motion capture system; consisting of a 10-camera Vicon system (Vicon Inc., Oxford, UK), a treadmill (Bertec Corp., Columbus, Ohio), 180-degree cylindrical projection screen system, and D-Flow software (MotekforceLink, Amsterdam, Netherlands). The Human Body Model (HBM) is a feature of the D-Flow software, which uses the 3D position of 14.00 mm retroreflective markers to calculate biomechanical gait parameters [15]. A set of 25 markers were placed by the same clinician according to the HBM (Fig. 1) [15]. Six additional markers (31 total) were placed bilaterally on the acromioclavicular process of the shoulder, ulnar process of the elbow, and the dorsal side of the wrist to measure arm swing. Position data were sampled at 100 Hz.

Walking speed was selected using the CAREN system “self-paced” feature. A self-paced treadmill speed algorithm, incorporating anterior-posterior pelvis position relative to the center of the treadmill, was used for all walking tests [16]. Participants were instructed to walk at a comfortable pace and were given a 5-minute warm-up period to acclimate to the self-paced treadmill before data collection was initiated. An image of a path progressing at the speed of the treadmill was projected onto the screen to simulate over-ground walking, and the treadmill remained at 0% grade throughout the trial. The treadmill was equipped with a non-restrictive harness and handrails, and participants wore comfortable walking shoes.

2.4. Procedure

Prior to biomechanical gait data collection, each participant completed the following tasks in a seated position to evaluate cognitive function under single-task (ST) conditions: N-back test evaluating working memory [17], serial-7 subtraction challenging attention and concentration, digit recall focusing on attention and working memory, verbal fluency evaluating semantic memory, and visual Stroop test looking at processing speed and attention. A two-minute duration was used for the ST walking and serial-7 subtraction task for comparison to the standardized 2-minute walk test. Verbal fluency was conducted using a 60-second trial. The N-back and Stroop tests were presented visually on the projection screen with letters or words displayed on the screen every two seconds during a 60-second trial [18]. All other tasks utilized auditory presentation, and were provided by the same test technician. Duration for the digit recall task was variable depending on the correct responses from the participant. The order of cognitive tasks under ST conditions was randomized across participants, via random number generator.

After the ST cognitive testing and the familiarization period on the self-paced treadmill, the cognitive tasks, in same order as the ST conditions, were performed while participants walked on the treadmill (DT). Participants were instructed to walk at a comfortable pace and were not instructed to prioritize one task over another. Following completion of all DT walks, a 2-minute ST walk was completed. Rest breaks were given between dual-task assessments as requested by the participant.

2.5. Biomechanical variables

Biomechanical data were parsed into the more affected (greatest symptom presentation in upper and lower extremities per MDS UPDRS-III) and less affected (least symptom presentation) sides.

Markers placed on the approximate center of the wrist were used to measure displacement during arm swing. The raw X, Y, Z coordinates were normalized to the pelvis to provide displacement relative to the body to account for variable subject locations within the motion capture volume [15]. Arm swing was normalized by