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Increasing speed to improve arm movement and standing postural control in Parkinson's disease patients when catching virtual moving balls

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ABSTRACT

Research has shown that moving targets help Parkinson's disease (PD) patients improve their arm movement while sitting. We examined whether increasing the speed of a moving ball would also improve standing postural control in PD patients during a virtual reality (VR) ball-catching task. Twenty-one PD patients and 21 controls bilaterally reached to catch slow-moving and then fast-moving virtual balls while standing. A projection-based VR system connected to a motion-tracking system and a force platform was used. Dependent measures included the kinematics of arm movement (movement time, peak velocity), duration of anticipatory postural adjustments (APA), and center of pressure (COP) movement (movement time, maximum amplitude, and average velocity). When catching a fast ball, both PD and control groups made arm movements with shorter movement time and higher peak velocity, longer APA, as well as COP movements with shorter movement time and smaller amplitude than when catching a slow ball. The change in performance from slow- to fast-ball conditions was not different between the PD and control groups. The results suggest that raising the speed of virtual moving targets should increase the speed of arm and COP movements for PD patients. Therapists, however, should also be aware that a fast virtual moving target causes the patient to confine the COP excursion to a smaller amplitude. Future research should examine the effect of other task parameters (e.g., target distance, direction) on COP movement and examine the long-term effect of VR training.

1. Introduction

Parkinson's disease (PD) patients experience cardinal symptoms such as bradykinesia and postural instability. Their arm movements tend to be slower and less forceful than those of controls [1,2]. In addition, their postural responses, including anticipatory postural adjustments (APA) and compensatory postural reactions, are usually slower and of smaller amplitude than those of controls [3–5]. PD patients also have difficulty modifying the magnitude and patterns of postural responses according to task demands [6]. Because many daily tasks require a person to make efficient movements while keeping balance, interventions to improve arm movements and postural responses are important for PD patients.

Accumulated evidence [7–10] has shown that the movements of PD patients can be improved by external (e.g., visual and auditory) cueing. Several studies have used moving targets as visual cueing to signal the timing of movement and showed the benefits of moving targets to improve arm movement [11–13] and trunk-arm coordination in PD patients who were sitting [14]. However, there has been no research examining the effect of moving targets on standing postural control.

Catching fly balls is a goal-directed functional task that is familiar and fun. Generally, the task is done while standing and requires the coordination of arm movement and postural control to successfully catch the ball while maintaining balance [15,16]. For PD patients, a moving ball provides external timing cueing, and, at the same time, requires temporal and spatial coordination of their

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arms to meet the trajectory of the ball [17]. Therefore, catching fly balls while standing appears to be a particularly appropriate training task for PD patients to improve their arm movement and standing postural control. Despite the potential contribution and frequent use of the standing-and-catching task in rehabilitation therapies, no quantitative analysis exists on how PD patients perform in such tasks. The therapeutic use of this task, however, calls for systematic manipulation of task parameters (e.g., ball velocity, distance, direction) and a detailed examination of their effects to allow the development of evidence-based interventions.

With the advance of technology, virtual reality (VR) has garnered growing attention for its promising applications in research and clinical practice. Using VR to provide moving targets has been shown to be as effective as using real moving targets to improve arm movement in PD patients [18]. However, the previous studies [14,18] examined the movement only while the participants were sitting. It is also important to investigate the effects of virtual moving targets on arm movement and postural control while standing. Using VR to offer fly balls has several advantages over physical reality. First, VR allows precise manipulation of ball speed, distance, and direction; such precision cannot be achieved in physical reality [19]. Additionally, VR provides a safe environment in which there is no risk of being hit by a ball.

Therefore, the purpose of this study was to examine the effects of ball speed on arm movement and standing postural control in PD patients when they were catching virtual moving balls. Because the center of pressure (COP) has been identified as a key parameter for monitoring the postural control system [20], it was used as an indicator of postural actions in response to moving-target cueing. Based on the research on moving-target cueing [11–14,18], we hypothesized that a fast ball would elicit faster and more forceful arm movement in PD patients than would a slow ball. In addition, because faster voluntary movement necessitates greater postural preparation than does slower movement [21], and because of the temporal requirement of the condition, we hypothesized that a fast ball would induce longer APA and faster COP movement than would a slow ball.

2. Methods

2.1. Participants

Twenty-one PD patients (8 women, 13 men; age, 64.76 ± 7.97 years; disease duration, 4.79 ± 3.06 years) participated in this study. Their inclusion criteria were: (1) diagnosed with idiopathic PD, (2) at Hoehn & Yahr stages [22] II or III, (3) stable medication use, (4) between 50 and 75 years old, (5) no serious cognitive deficits (score $\geq$24 on the Mini-Mental Status Examination), (6) normal or corrected-to-normal vision and hearing, (7) no history of neurological conditions other than PD, and (8) no musculoskeletal disorders affecting arm movement. Of these participants, 17 were at Hoehn & Yahr stage II, and 4 at stage III.

In addition, we recruited 21 age- and gender-matched controls (8 women, 13 men; age, 64.71 ± 7.83 years). There were no significant differences between the PD and control groups in age ($t = 0.019$, $p = 0.985$), weight (PD: 61.81 ± 8.90 kg vs. controls: 62.87 ± 9.04 kg; $t = 0.46$, $p = 0.65$), or height (PD: 157.23 ± 14.89 cm vs. controls: 161.58 ± 8.05 cm; $t = 1.18$, $p = 0.25$). Recruitment and testing procedures were in accord with the ethical standards of our medical center, and the protocol was approved by our institutional review board. All participants signed an informed consent before the experiment began.

2.2. Instruments

A projection-based VR system was used, including a personal computer, a 3-m screen, 2 projectors with high lumens, and polarized glasses. The VR system was connected with a motion tracking system (Patriot; Polhemus Inc., Colchester, VT, USA) and a balance board (Wii; Nintendo Inc., Kyoto, Japan). The Patriot system was used to record participant's arm movements. The Patriot system was checked in our lab and showed an error rate of 0.3–0.6% and an intraclass correlation coefficient of 0.97–0.99. The Wii balance board, part of the popular video game WiiFit, is portable, inexpensive, and widely available. Tests of the Wii balance board suggest that it is a valid and reliable tool for assessing single-leg and double-leg standing balance [23].

2.3. Procedures

Each participant stood on a Wii balance board with one Patriot motion sensor attached to the back of each hand. The participant wore polarized glasses to experience the virtual environment. The starting position of their hands was arms aligned with the sides of the body and elbows flexed at 90°. The images on the screen were set up so that the participant could see a ball machine in the middle of the screen and two virtual hands on the bottom of the screen. The movement of the two virtual hands corresponded to the participant's own hand movements.

A repeated-measures design was used. All participants completed the slow-ball condition first and then the fast-ball condition. This testing order was decided to reduce the frustration of doing the fast-ball condition first, and in view of clinical situations that generally progress from easy to difficult, because our pilot study found that PD patients had a very low success rate if they did the fast-ball condition first.

In each condition, a virtual ball (8 cm in diameter) was projected from the ball machine and flew to in front of the participant, with the point of ball-catching set at a distance of 100% of their arm's length. The participant was required to catch the ball with both hands. We manipulated the speed of the ball in terms of the time it took from the moment it appeared to the moment it arrived at the point of ball-catching: 1.2 s (slow) vs. 0.8 s (fast). The movement of the ball followed the principle of gravity; thus, a slow ball had a higher trajectory than did a fast ball.

For each condition, the participant practiced until they could successfully catch three consecutive balls. After practice, the participant did 15 test trials for each condition, with a 5-min break between conditions. Only data from successful test trials were analyzed.

2.4. Dependent measures

We examined success rate and kinematic variables. A trial was considered successful when the distance between the midpoint of the participant's hand sensors and the center of the ball was less than 9 cm (the radius of the ball + 5-cm error range). For kinematic measures, velocity was derived from position data that were filtered using a moving-average filter. The cutoff value to define movement onset was set at 5% of peak velocity. *End of movement* was defined as the time when the computer detected a successful catch. Movement time was calculated as the length of time it took to execute the arm movement. Faster movements have shorter movement times [2,24]. Peak velocity is the highest instantaneous velocity during the arm movement. The higher the peak velocity, the more forceful the movement [1,25].

The traces of COP were derived from the Wii balance board. The cutoff value to define the onset of COP movement was set at 10% of peak velocity. *End of COP movement* was defined the same as that of arm movement. Movement time is the length of time from the onset to the end of COP movement. APA was defined as the postural movements occurring before the onset of arm movements.