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Trunk–arm coordination in reaching for moving targets in people with Parkinson's disease: Comparison between virtual and physical reality

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ABSTRACT

We used a trunk-assisted prehension task to examine the effect of task (reaching for stationary vs. moving targets) and environmental constraints (virtual reality [VR] vs. physical reality) on the temporal control of trunk and arm motions in people with Parkinson's disease (PD). Twenty-four participants with PD and 24 age-matched controls reached for and grasped a ball that was either stationary or moving along a ramp 120% of arm length away. In a similar VR task, participants reached for a virtual ball that was either stationary or moving. Movement speed was measured as trunk and arm movement times (MTs); trunk–arm coordination was measured as onset interval and offset interval between trunk and arm motions, as well as a summarized index-desynchrony score. In both VR and physical reality, the PD group had longer trunk and arm MTs than the control group when reaching for stationary balls ($p < .001$). When reaching for moving balls in VR and physical reality, however, the PD group had lower trunk and arm MTs, onset intervals, and desynchrony scores ($p < .001$). For the PD group, VR induced shorter trunk MTs, shorter offset intervals, and lower desynchrony scores than did physical reality when reaching for moving balls ($p < .001$). These findings suggest that using real moving targets in trunk-assisted prehension tasks improves the speed and synchronization of trunk and arm motions in people with PD, and that using virtual moving targets may

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induce a movement termination strategy different from that used in physical reality.

1. Introduction

Parkinson's disease (PD) is a progressive neurodegenerative disorder associated with basal ganglia dysfunction, which causes impairments in the temporal regulation of movements (Delwaide & Gonce, 1993; Wang, Bohan, Leis, & Stelmach, 2006). Research has reported that movements in people with PD become increasingly slow when doing tasks involving long sequences or different movement components (Agostino, Berardelli, Formica, Accornero, & Manfredi, 1992; Benecke, Rothwell, Dick, Day, & Marsden, 1987a, 1987b). The observed movement slowness results not only from the prolonged movement time of individual movement components (e.g., reach and grasp), but also the delay between movement components, which suggests impaired ability in the timing and coordination of individual components (Bennett, Marchetti, Iovine, & Castiello, 1995; Castiello, Stelmach, & Lieberman, 1993).

However, relatively little attention has been given to the coordination of different body segments (e.g., trunk and arm) in people with PD. In daily life, people are confronted with situations in which an object is located beyond arm's reach; therefore, to extend the reach distance, the trunk becomes involved in the reach to the target (Wang & Stelmach, 2001). Limited research on trunk–arm coordination in PD showed that in trunk-assisted prehension tasks, people with PD had longer onset and offset intervals between trunk and arm motions than did healthy controls (Poizner et al., 2000; Wang et al., 2006). These results suggest that, while healthy adults coordinate the trunk and arm movements as a single unit, people with PD do not coordinate these movements in the same manner. Slowed movement and segmented trunk–arm coordination restrict the ability to efficiently reach beyond arm's length and thus have a negative influence on functional performance in daily life (Alves, Forsaa, Pedersen, Dreetz Gjerstad, & Larsen, 2008; Muslimovic et al., 2008). A significant part of rehabilitation for people with PD is to improve movement speed and synchronization. Understanding the temporal control of trunk–arm coordination in response to task and environmental constraints may provide insight into the underlying control processes and would help shape treatment strategies for rehabilitation.

Dynamical systems theory proposes that movement patterns emerge from the interplay of personal, task, and environmental constraints (Newell, 1986). This framework provides a guideline for rehabilitation practitioners to analyze performance and to manipulate constraints in order to influence movement patterns (Newell & Valvano, 1998). A potentially important task constraint is the status of the objects involved: whether they are stationary or in motion (Gentile, 1987; Magill, 2011). Healthy adults are sensitive to a target's motion and use characteristics of the target's motion when generating their own movements (Carnahan & McFadyen, 1996; Mason & Carnahan, 1999). For people with PD, a moving target provides visual motion stimuli that may serve as an external trigger and compensate for the impaired internal timing cueing caused by basal ganglia dysfunction. Some studies examined the effect of fast-moving targets on the kinematics of reach and grasp (Majsak, Kaminski, Gentile, & Flanagan, 1998; Majsak, Kaminski, Gentile, & Gordon, 2008; Schenk, Baur, Steude, & Botzel, 2003). Their results indicated that a moving target improved the speed of reaching movement in participants with PD to a level similar to that in healthy controls (Majsak et al., 1998, 2008). Except for the grasping component, the movement speed in participants with PD was only slightly improved by the moving target, and it remained impaired compared with controls (Schenk et al., 2003). Considering the differential effects of moving targets on different movement components, it is important to examine whether and to what degree moving targets improve the speed and synchronization of trunk and arm motions during trunk-assisted prehension tasks in people with PD.

Newly developed virtual reality (VR) technology provides a channel for examining the influence of environmental constraints. VR has garnered growing attention for its promising applications in research and clinical practice. The controllability of the computer-generated conditions in VR allows