Neuropsychologia 42 (2003) 82–94

NEUROPSYCHOLOGIA

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Deficits in the evolution of hand preshaping in Parkinson's disease

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Received 12 June 2002; received in revised form 13 February 2003; accepted 3 June 2003

Abstract

Parkinson's disease (PD) results in various types of motor impairments including bradykinesia, tremor and rigidity. Recent research has implicated more fundamental processes at the source of the observed motor deficits. Among these, problems in the sequencing and/or timing of complex movements and in the execution of internally-guided tasks. Furthermore, PD patients exhibit procedural learning deficits which may complicate the interpretation of experimental results of studies involving novel sensorimotor tasks. The reach-to-grasp movement is a complex, overlearned sensorimotor task consisting of two semi-independent components, a relatively simple reach or *transport* phase and a more complex manipulation or *prehension* phase. In the present study, we used a novel technique in order to study the evolution of hand preshaping during the reach-to-grasp movement of PD patients and age-matched controls to objects of different shapes in three different spatial locations. Our results indicate that while PD patients are able to specify movement direction as well as controls, their hand preshaping exhibits substantial impairments. Other prehension measures, such as the time to peak aperture (TPA), indicate that PD patients delayed execution of the grasp until visual feedback of their hand was available. Overall, our results suggest that PD patients' internal guidance processes are severely disrupted, having to rely on visual feedback in order to modulate their hand shape to fit the contours of the target objects during a reach-to-grasp movement.

Keywords: Prehension; Basal ganglia; Hand configuration

1. Introduction

A number of motor and cognitive deficits have been described in patients with Parkinson's disease (PD). Among the classic motor impairments are bradykinesia, rigidity, tremor and loss of postural reflexes. Nevertheless, closer scrutiny of the physiological and behavioral manifestations of the disease have resulted in the characterization of a range of deficits of a more fundamental nature, such as problems in the timing, sequencing, and planning of motor programs (Benecke, Rothwell, Dick, Day, & Marsden, 1987; Harrington & Haaland, 1991; Weiss, Stelmach, & Hefter, 1997). Isenberg and Conrad (1994) found that PD patients showed impairments in synchronizing movement path segments when pointing with different movement velocities to targets at different distances, and concluded that PD patients show deficits in the specification of movement parameters that are time-dependent. We have found that PD patients show marked intersegmental timing deficits when asked to point to 3D targets by combining movement of the arm with a forward bending of the trunk. While control subjects synchronized onsets and offsets of fingertip and trunk motions, the PD patients produced asynchronous movements with large temporal intervals between onsets and offsets of the arm and trunk (Poizner et al., 2000). Likewise, Benecke et al. (1987) in a classic study showed that PD patients exhibit a sequencing impairment during the performance of a complex multi-step movement, while at the same time performing normally for simpler movements. It has become clear through these and other studies that the performance of complex movements is particularly affected in PD, and that there is impaired temporal specification and coordination of movement components in these complex actions (Agostino, Berardelli, Curra, Accornero, & Manfredi, 1998; Alberts, Saling, Adler, & Stelmach, 2000; Gentilucci & Negrotti, 1999). Furthermore, it has also been

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doi:10.1016/S0028-3932(03)00150-7

reported (Flowers, 1976) that PD motor performance is compromised in the absence of sensory feedback. A number of studies in our laboratory (Adamovich, Berkinblit, Hening, Sage, & Poizner, 2001; Poizner et al., 2000) and others (Beuter, Milton, Labrie, Glass, & Gauthier, 1990; Flowers, 1976; Georgiou et al., 1993) have confirmed this notion. Such evidence has lead to the proposal that PD may result in a loss of internally-guided motor behavior (Flowers, 1976) and consequently, in the preferential use of a more sensory-controlled or closed-loop response mode.

The use of an extensively studied and well-described natural complex movement presents many advantages in this respect: there is no need for skill acquisition, which has been found to be impaired in PD subjects (Graybiel, 1995). The components of the movement have been well parameterized (Jeannerod, 1997). The reach-to-grasp movement is generally thought to consist of two semi-independent elements: a reaching or *transport* component, and a grasping or *prehension* component (Jeannerod, 1981, 1984). The complexity of this action is compounded by the fact that the final configuration of the hand during the reach-to-grasp movement is determined by intrinsic features of the target object such as size and shape (Jeannerod, 1984). Thus, in order to reach for and grasp an object, the subject must not only transform the spatial location of the object into an appropriate pattern of shoulder and elbow rotations in order to transport the arm to the object, but must also transform the visual size, shape and orientation of the object into an appropriate pattern of finger and wrist movements to grasp the object. In a pioneering study of how normal subjects reach to and grasp objects of different shapes, Santello and Soechting (1998) showed that finger flexion and extension is modulated during the reach in order to define a hand posture favorable for the grasp of the target object according to its shape. In a more recent study, we have shown that hand preshaping may take place as early as 30% of the movement duration during the reach-to-grasp movement, indicating that normal subjects execute the reach and grasp components of the movement in parallel and do so using a predictive strategy (Schettino, Adamovich, & Poizner, 2003). Importantly, the various components within a reach-to-grasp movement, though executed in parallel, appear to be specified at different points in time as the movement evolves (Santello & Soechting, 1998). Movement direction appears to be specified very early on in the movement, with some studies finding direction specified at movement onset (Fu, Suarez, & Ebner, 1995; Georgopoulos & Massey, 1988; see also Messier & Kalaska, 2000). In contrast, preshaping of the hand occurs much later (Santello & Soechting, 1998; Schettino et al., 2003).

While no study has yet investigated PD performance in reaching to and grasping objects of different shapes, the reach-to-grasp movement involving the index finger and the thumb has been the focus of several recent studies in PD patients (Bonfiglioli, De Berti, Nichelli, Nicoletti, & Castiello, 1998; Castiello, 1999; Castiello & Bennett, 1997; Castiello, Bennett, Bonfiglioli, & Peppard, 2000; Castiello, Bennett, & Scarpa, 1994; Jackson, Jackson, Harrison, Henderson, & Kennard, 1995). Castiello, Stelmach, and Lieberman (1993) found that PD patients showed a delay in the initiation of the prehension phase relative to the beginning of the transport phase of the grasping movement. Interestingly, other studies, such as Castiello and Bennett (1997), Jackson et al. (1995) and Bonfiglioli et al. (1998), found relatively few deficits in PD patients in reach-to-grasp tasks for objects of different sizes. More recently, Castiello (1999) examined the modulation of the grasping movements of PD patients to a perturbation in the size and location of the target object. The results indicated that PD patients were significantly slower than normal controls both in the transport *and* prehension phases. Also, some parameters of the prehension phase, such as peak aperture (PA), were significantly reduced in this group. Finally, the elements of the perturbed grasping movement produced in parallel by the control subjects, were performed sequentially in PD patients. Likewise, Alberts et al. (2000) found that PD patients showed deficits in the consistency of the timing of aperture closure and in the coordination of the transport and grasp. Interestingly, studies of deaf signers who had PD showed that they did not appropriately time and link changes in hand configurations with ongoing movements during signing (Brentari, Poizner, & Kegl, 1995). They also showed difficulty in timing and coordinating finger, thumb and wrist movements in the complex movement sequences of finger-spelled words (Tyrone, Kegl, & Poizner, 2000). Moreover, this was definitely a matter of coordination between components since the deficits in the timing of individual components could not be explained by the slowing of movements.

In the present study, we set out to investigate the extent to which PD patients are impaired in the naturally complex task of hand preshaping during grasping objects of different shapes. In order to do so, 10 mild to moderate PD patients in the off-medication state and 8 age-matched controls were tested in a grasping task involving a reach-to-grasp movement towards objects of three different shapes located in three different directions from the body. As mentioned earlier, the specification of movement direction has a different time course from the specification of hand shape. Moreover, grasping objects of different shapes requires a more complex timing and coordination of the joints of the arm and hand than does grasping objects of different sizes, since individuated finger movements and not just hand aperture needs to be modulated. Thus, we hypothesized that patients with PD, who may have particular difficulty in timing and coordinating parallel motor processes in complex actions, would be unable to properly preshape their hands as the reaching component of the movement unfolded. Moreover, due to the complexity of the task compared to two-finger prehension, it is possible that PD patients will exhibit a larger reliance on visual feedback in order to accomplish the task appropriately. Conversely, it was predicted that direction specification would not exhibit significant differences between PD subjects and controls due to the fact that during the task,