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Inter-limb coupling during diadochokinesis in Parkinson's and Huntington's disease

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ABSTRACT

Patients with neurodegenerative diseases often exhibit deficits in bimanual coordination. One characteristic of bimanual movements is inter-limb coupling. It is the property of motor performance harmonization between hands during a bimanual task. The objective of this study was to identify whether spatial and temporal inter-limb coupling occurred in Parkinson's disease (PD) and Huntington's disease (HD) patients. Twenty-three PD patients and 15 healthy controls were tested. Data from 12 choreic HD patients were also taken from a databank. Participants were asked to perform a unimanual and bimanual rapid repetitive diadochokinesis task. The difference between hands in mean amplitude and mean duration of cycles was computed in the unimanual and bimanual tasks for each group. Results show that healthy controls exhibited temporal and spatial inter-limb coupling during the bimanual diadochokinesis task. Conversely, PD and HD patients exhibited temporal inter-limb coupling; but failed to exhibit spatial inter-limb coupling during the bimanual diadochokinesis task. Furthermore, HD patients exhibited reduced levels of structural coupling compared to controls and PD patients. These results suggest that alterations in basal ganglia-thalamo-cortical networks due to PD and HD do not affect temporal inter-limb coupling. However, common pathophysiological changes related to PD and HD may cause altered spatial inter-limb coupling during a rapid repetitive bimanual diadochokinesis task.

1. Introduction

Inter-limb coupling is a phenomenon whereby each of the upper-limbs tends to take on characteristics of the intended movement of the other. For instance, when homologous muscle groups are recruited during a bimanual task, isometric force exerted by one limb may increase the activity of the motor neuron pool of the contralateral limb (Davis, 1942). Lazarus and Stelmach (1992) observed that healthy individuals benefit from performing a simultaneous isometric contraction while moving as rapidly as possible with the other limb. They suggested that using the same muscle groups in both limbs increased the potential for motor overflow from the limb performing the isometric contraction. This motor overflow in the contralateral limb has been observed in normal children and in adults under conditions of extreme force, fatigue, or stress (Gregg et al., 1957; Podivinsky, 1964; Wolff et al., 1983) as well as in healthy adults during normal conditions (Sherwood, 1991, 1994, 2004, 2006, 2007; Sherwood and Nishimura, 1992, 1999; Heuer et al., 1998; Sherwood and Sullivan, 1999). Interestingly, inter-limb coupling was shown to improve motor performance of the hemiparetic arm of stroke patients (Harris-Love et al., 2005).

Performing bimanual movements requires a complex control network that is dependent on the complexity and degree of familiarity of the task (Swinnen, 2002). The networks involved in controlling bimanual movements encompass both cortical and subcortical structures. Studies demonstrated that the cortical network involves primary and accessory motor areas (Sadato et al., 1997; Goerres et al., 1998; Stephan et al., 1999a,b; Toyokura et al., 1999; Jancke et al., 2000; Kermadi et al., 2000; Deiber et al., 2001; Immisch et al., 2001) as well as the corpus callosum (Eliassen et al., 1999; Serrien et al., 2001). At the sub-cortical level, the thalamus (Hoover and Strick, 1993) and basal ganglia (Wannier et al., 2002) were shown to participate in bimanual coordination. It is therefore not surprising that individuals with neurodegenerative diseases, such

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as Parkinson's disease (PD) and Huntington's disease (HD), display deficits in bimanual diadochokinesis (Brown et al., 1993; Joebges et al., 2003; Muller and Harati, 2010) since those pathologies cause dysfunctions of sub-cortical and cortical structures implicated in bimanual coordination.

Indeed, several studies have demonstrated that bimanual coordination is hampered in PD patients (Brown et al., 1993; Johnson et al., 1998; Almeida et al., 2002; Byblow et al., 2002; Alberts et al., 2004, 2008; Ponsen et al., 2006; Nieuwboer et al., 2009; Stegemoller et al., 2009; Wu et al., 2010; Brown and Almeida, 2011; Almeida and Brown, 2013). These deficits range from the organization and execution of simultaneous and sequential movements of the upper limbs (Schwab et al., 1954; Benecke et al., 1987; Marsden, 1989; Harrington and Haaland, 1991; Klockgether and Dichgans, 1994; Bennett et al., 1995; Weiss et al., 1997; Alberts et al., 1998; Johnson et al., 1998), to decreased degree of phasing accuracy and stability (Swinnen et al., 1997; Johnson et al., 1998; Serrien et al., 2000), and several others. However, when the same tasks are performed simultaneously for each hand, some studies examining bimanual coordination in PD observed no deficits compared to controls (Cohen, 1970; Stelmach and Worringham, 1988; Samuel et al., 1997; Johnson et al., 1998; Almeida et al., 2002; Song et al., 2010). Specifically, these studies have failed to find PD related deficits in tasks that involve in-phase coordination, despite their occurrence during asymmetric movements. Johnson et al. (1998) also demonstrated that PD patients were able to maintain in-phase movements at slow and fast speeds; although they were significantly less accurate and less stable than healthy controls. This supports the hypothesis that in-phase modes of coordination may promote bimanual coordination through motor overflow, making the task easier to perform (Lazarus and Stelmach, 1992).

The objective of the current protocol was to identify whether PD patients exhibit deficits in inter-limb coupling during an in-phase bimanual rapid repetitive diadochokinesis task by assessing temporal and spatial properties of movement independently. We hypothesized that, in light of the pathophysiology of the disease, deficits in inter-limb coupling may be present in some features of inter-limb coupling. A second objective was to compare the results obtained in PD patients to choreic HD patients in order to relate inter-limb coupling between both pathologies and assess whether shared pathophysiological impairments may be involved in the spatial and temporal properties of inter-limb coupling. HD patients have previously been shown to have very little deficit in simple bimanual tasks (Johnson et al., 2000; Duval et al., 2009). Rather, they exhibit marked decrease in motor performance as the bimanual task becomes more complex (Johnson et al., 2000; Serrien et al., 2002). Specifically, Brown et al. (1993) demonstrated that while HD patients did exhibit deficits in bimanual motor performance, these deficits were smaller than those observed in PD patients. As such, we hypothesized that HD patients would exhibit less deficits in inter-limb coupling than PD patients.

2. Experimental procedures

2.1. Participants

Twenty-three patients diagnosed with idiopathic PD based on the American Academy of Neurology criteria (Suchowersky et al., 2006) that were in the advanced stages of the disease (mean UPDRS-III 27.9 ± 12.8 *off* medication; mean Hoehn & Yahr score of 3; range of 2–4), and 15 healthy control subjects participated in the current study. PD patients were tested without having taken their medication; after a withdrawal period of at least 10 h (overnight). In addition, data from 12 patients diagnosed with adult-onset HD and presenting with chorea were obtained from a databank of patients previously tested within our laboratory. Clinical characteristics of the HD patients and some characteristics of motor performance, other than those presented here, have been previously published (Fenney et al., 2008a,b) (note that only data from patients 2, 3, 4, 5, 7, 8, 9, 10, 12, 13, 14, and 15 were used in the current study as the others had missing data). See Table 1 for demographic characteristics of participants. While it was not possible, for feasibility reason, to match controls, PD, and HD patients, the mean age of all three groups is not statistically different and thus; we feel that comparisons can be made. Participants signed the informed consent form. This study was approved by the institutional ethics research board.

Table 1
Demographic characteristics of participants.

	Controls	PD patients	HD patients
N	15	23	12
Gender	5 M; 10 F	15 M; 8 F	4 M; 8 F
Age (years)	59.5 ± 11.4	57.6 ± 7.8	56.6 ± 11.3
Years since diagnosis		11.1 ± 3.2	6.8 ± 5.3

2.2. Task

We opted to use an in-phase rapid repetitive diadochokinesis task performed unimanually and bimanually to assess spatial and temporal properties of inter-limb coupling because rapid alternating movements are associated with activation of the basal ganglia (Mink and Thach, 1991; Johnson et al., 2000); making this task ideal to observe deficits in bimanual coordination in PD and HD; basal ganglia dysfunction being a hallmark of both diseases. Furthermore, this task has relatively large amplitude in displacement and velocity, thereby reducing the likelihood of biomechanical effect. It is also simple enough to minimize greatly the influence of cognitive deficits known to frequently occur in both PD and HD. The basic assumption of this design is that when a task is performed unimanually, optimal performance for a given hand is obtained. By computing the difference between the performance observed in each hand, the score obtained should be highest when the task is performed unimanually as there is no motor overflow leading to inter-limb coupling during unimanual movements. By comparing the score obtained during the bimanual condition to the one obtained in the unimanual condition, it is possible to assess whether inter-limb coupling occurred during the given task. This method is similar to the symmetry ratio used by Harris-Love et al. (2005) where they assessed inter-limb coupling in hemiparetic patients. In effect, this method compares the relative relationship of a given movement property (see Section 2.4) between two effectors (right and left hands) during two conditions (unimanual and bimanual).

2.3. Procedure

Participants were seated on an armless chair with elbows bent 90° at their sides. They were asked to hold, in each hand a foam handball that was attached to angular displacement sensors. Participants were first instructed to maintain a "stable" position with the hands in a neutral position for 15 s. Participants were then instructed to perform pronation–supination of the dominant hand with as fast and as complete a rotation as possible, for a period of 10 s, while keeping the elbows by the side of their bodies. Then, participants were asked to return to the stable state with the hands in the neutral position for the remaining 15 s. In order to learn the task, participants were first instructed to perform a series of slow cycles with each hand individually and then simultaneously, so as to observe their maximal excursion. Then, participants were asked to perform a series of fast cycles with excursions as complete as