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Hand function in multiple sclerosis: Force coordination in manipulation tasks

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ABSTRACT

Objective: To evaluate the methodology for exploring the specific aspects of functional impairment in multiple sclerosis (MS) through the pattern of forces exerted in various manipulation tasks.
Methods: Twelve mildly involved MS patients (EDSS 2.5–5.5) and 12 healthy controls performed various static and dynamic manipulation tasks with an instrumented device that recorded the grip (*G*; normal to the digit device contact area) and load force (*L*; tangential force that causes lifting).
Results: MS patients consistently displayed lower indices of task performance (as assessed by the ability to produce the required *L* profiles) and force coordination (as assessed by *G*/*L* ratio, coupling of *G* and *L*, and *G* modulation) than the healthy controls across all tested tasks.
Conclusions: The applied methodology could be sensitive enough to detect the hand dysfunction in mildly involved individuals with MS. Particularly recommended for future evaluations of the impairment of hand function could be a simple lifting task and the static task of tracing a gradually changing *L*, as well as the variables depicting both the task performance and *G*/*L* ratio.
Significance: The applied methodology could be developed into a standard clinical test for the assessment of hand function in MS and, possibly, in other neurological diseases.

1. Introduction

Independent living heavily depends on the ability to manipulate various objects in everyday life. Hand dysfunction regarding a limited manipulation ability is commonly seen in centrally or peripherally damaged neurological patients, such as in stroke (Nowak and Hermsdorfer, 2003a), Huntington's (Serrien et al., 2002), Parkinson's (Ingvarsson et al., 1997), motor neuron disease (Nowak and Hermsdorfer, 2002), or in peripheral neuropathy (Thonnard et al., 1997). In the clinical practice, hand dysfunction has been assessed either by simple quantitative tests, such as maximum grip strength, range of motion of the fingers or by timed simple actions, or by subjective qualitative assessments (for details see further text).

The research done over the last few decades suggests that the hand function can be assessed through the kinetic analysis of various functional tasks. Specifically, the manipulation of fixed and free moving objects appears to be associated with high coordination of two particular force components. In a simple mechanical representation of lifting (e.g., lifting a glass of water), the load force (*L*) acts in parallel to the digits-object contact area and performs the lifting or holding of an object, but at the same time tends to cause slippage. Grip force (*G*) acts perpendicularly to the contact area. It helps in controlling the manipulated object hold within the grasp and also prevents the slippage. A consistent finding over a body of the literature is that the changes in *G* are highly coordinated with the changes in *L* without any time lags between them and therefore, the coordination appears to be based on anticipatory neural control mechanisms (Flanagan and Wing, 1995; Johansson and Westling, 1984). The final outcome of this coordination is a stable *G*/*L* ratio that is highly adjusted to the friction coefficient to provide *G* that is slightly above the minimal level that prevents the slippage (Johansson, 1998). In addition to *G*/*L* ratio, *G* and *L* coordination has been often assessed through a force coupling (as assessed by both high correlation coefficients and virtually no time lag between *G* and *L* (Flanagan and Tresilian, 1994; Zatsiorsky et al., 2005)) and a high *G* modulation with respect to the changes in *L* (Flanagan et al., 1993). Taking into account the essential role of *G* and *L* in manipulation activities, it should not be surprising that neurological patients and other populations known for impaired hand function consistently show deteriorated force coordination when performing various manipulation tasks. For example, along with an elevated *G* (Nowak and Hermsdorfer, 2002, 2003b; Rost et al., 2005; Serrien and Wiesendanger, 1999), uncoordinated changes in *G* and *L* have been consistently observed across neurological diseases (Fellows et al., 1998; Gordon et al., 2006; Hermsdorfer et al., 2003; Nowak et al., 2002, 2003).

Interestingly, apart from *G* and *L* coordination, the coordination of *L per se* has been mainly neglected in the kinetic analysis of hand function in both healthy and various clinical populations. Namely,

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an accurate temporal pattern of *L* is required for precise manipulation, such as repositioning of an object, using a tool, or providing a postural support from an externally fixed object. Our recent findings suggest that, in addition to the above discussed *G* and *L* coordination, the accuracy of the exerted *L* pattern could reveal both the effect of hand dominance and the differences in manipulation performance between healthy participants and neurological patients (de Freitas et al., 2007; Ferrand and Jaric, 2006; Krishnan et al., 2008; Marwaha et al., 2006).

One of the most common neurological diseases of the central nervous system is multiple sclerosis (MS). It is a demyelinating, autoimmune disorder associated with sensory-motor disintegration, motor impairment, postural imbalance, intention tremor, ataxia and impaired motor coordination (Matthews, 1991). The socioeconomic impact of this disease is exceptionally high because of its high prevalence and incidence among young adults, long duration, physical disability and the need for assistance. A widely prevalent clinical symptom in MS is impairment of hand function that has been directly or indirectly assessed by various clinical tests. The most often applied clinical test for a general assessment of MS patients has been the Expanded Disability Status Scale (EDSS; (Kurtzke, 1983)) although its validity (Rossier and Wade, 2002) and reliability (Noseworthy et al., 1990; Whitaker et al., 1995) has been often questioned. A more specific Multiple Sclerosis Functional Composite Measure (MSFC) has been also developed (Cutter et al., 1999). An integral part of MSFC is the assessment of the upper extremity function by the 9-hole peg test (Grice et al., 2003) which is a timed test of a simple motor activity. Similarly, the Jebsen–Taylor test is based on a number of timed tests that mimic daily motor activities and it has been applied on a variety of neurological patients (Jebsen et al., 1969). Therefore, one could conclude that most of the contemporary clinical tests of hand function appear to be based either on the qualitative subjective assessment or on the timed simple motor actions. As a result, the above discussed elaborate force coordination that characterizes manipulation activities in healthy individual could provide an opportunity not only to assess specific aspects of impairment in various neurological diseases such as MS, but also to construct quantitative clinical tests of hand function.

We recently developed a methodology for the assessment of force coordination in uni- and bimanual static manipulation tasks (Jaric et al., 2005, 2006; Krishnan et al., 2008; Marwaha et al., 2006). Both the indices of *G* and *L* coordination and the indices of task performance based on exertion of the prescribed *L* profile proved to be sensitive enough to detect various effects, such as of the rate of change of *L* and the type of the task performed (Jaric et al., 2005, 2006), or of the hand dominance (de Freitas et al., 2007; Ferrand and Jaric, 2006). Of particular importance for this study could be our recent findings obtained from mildly involved MS patients. Although most of them claimed that they had no problems in daily manipulation activities, their ability to accurately exert the instructed *L* profile proved to be impaired when compared to healthy controls, while their ability to coordinate *G* and *L* (excluding somewhat elevated *G*/*L* ratio) seemed to be mainly unaffected (Krishnan et al., 2008; Marwaha et al., 2006). Therefore, we concluded that in mildly involved MS patients 'the deterioration in the ability for precise control of external forces and over-gripping could precede the decoupling of *G* and *L* and decreased *G* modulation in early phases of the disease' (Krishnan et al., 2008). Nevertheless, the results of both studies suggested that the methodological approach based on the force coordination in static manipulation tasks could be sensitive enough to be applied in the assessment of hand function in MS and probably, other neurological diseases.

Within this study, we extended our previous research on individuals with MS by introducing several changes. First, we decided to evaluate simpler tasks regarding both the instructed force profiles and task conditions. Second, instead of a somewhat complex, expensive and bulky device used in previous studies, we designed a simplified and a relatively small and light device containing only two miniature single-axis force transducers. Finally, we intended to relate our findings with the assessments based on standard clinical tests. The motivation for these changes came from the above discussed need for a development of a clinical tool for quantitative testing of hand function. Various manipulation tasks were tested and standard dependent variables depicting both the task performance and the force coordination were obtained. In particular, this study was designed in line with three main aims. The first one was to evaluate the impairment of the hand function of MS patients as assessed through the dependent variables depicting both the task performance and force coordination. Specifically, we hypothesized that the patients would demonstrate impaired force coordination across most of the dependent variables, and not only in the task performance and *G*/*L* ratio as the mildly involved patients had demonstrated in our previous studies. The second aim was to reveal both the manipulation tasks and the particular dependent variables that demonstrate the most prominent differences between the tested patients and healthy controls. The third aim was to evaluate the concurrent validity of the dependent variables with respect to frequently applied clinical tests of hand function. Therefore, the findings of this study were expected to reveal specific aspects of the hand function impairment in MS and to evaluate the validity of the applied methodological approach. Note also that MS is the most diverse among neurological disorders both regarding the localization of damage of the neural tissue and regarding the associated clinical and functional symptoms. Therefore, the expected findings could be partly extended to other neurological diseases, providing a basis for developing a standard testing tool for assessment of hand function.

2. Materials and methods

2.1. Participants

Considering the higher prevalence of MS in females (60–75%) (Whitacre, 2001), a larger proportion of females when compared to males were selected for the experiment. Specifically, 9 female and 3 male MS patients (age range 39–65 years, mean ± SD 52.6 ± 7.1) and an equal number of age and gender matched healthy individuals (age range 33–67 years, mean ± SD 50.0 ± 8.4) participated in the study. MS patients were recruited from the MS Clinic at the Physical Therapy Department of the University of Delaware, while the healthy controls were recruited by public advertisement. The experimental procedure was approved by the Human Subjects Review Board of the University of Delaware and the participants provided their informed consent in accordance to the Declaration of Helsinki. All MS patients and healthy controls were right hand dominant, except for a single healthy control, as assessed by the Edinburgh Inventory (Oldfield, 1971).

An experienced neurologist screened the MS patients and evaluated them on the EDSS. In order to control for the heterogeneity of the expression of the disease, the following inclusion criteria were adopted: the patients were capable of independent living, they also had a normal or corrected to normal vision, the 9-hole peg test time was less than a minute and the Jebsen–Taylor test time did not exceed 5 min. Patients were excluded if they had a history of psychiatric or other medical illnesses, drug or alcohol abuse, or if they were unable to perform the experimental tasks.

2.2. Experimental device

The experimental device used in the study consisted of a single handle (total length 8.5 cm and the grasping aperture 2.5 cm) that