Grip force control during simple manipulation tasks in non-neuropathic diabetic individuals

P.B. de Freitas *, K.C.A. Lima

Motion Analysis Lab, Graduate Program in Human Movement Sciences, Cruzeiro do Sul University, Rua Galvão Bueno, 868, Liberdade, São Paulo 01506-000, SP, Brazil

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HIGHLIGHTS

- The hand function of non-neuropathic diabetic individuals was assessed using traditional hand function tests and instrumented handles.
- Performance in two traditional hand function tests and maximum grip strength were not affected by diabetes.
- Surprisingly, non-neuropathic diabetic individuals adopted lower safety margin than controls during a simple object manipulation.

ABSTRACT

Objective: To assess hand function and grip force (GF) control in non-neuropathic diabetic individuals using traditional hand function tests and instrumented handles that provide information about the underlying neural mechanisms controlling simple manipulation tasks.

Methods: Twelve diabetic individuals (31–60 years-old) without neuropathy and 12 controls performed traditional functional tests (i.e., nine hole peg test, Jebsen–Taylor test, and maximum grip strength test) and were tested for GF control in two situations: holding a free moving instrumented handle and isometrically pulling fixed handles. Task performance in the tests and safety margin (SM – percentage of GF above the minimum needed to hold the handle) were the main dependent variables assessed.

Results: There was no difference between diabetics and controls in any functional test and in SM in isometric pulling task. However, diabetics presented around twice lower SM than controls in the free holding task.

Conclusions: Diabetics showed no impairment in functional manipulation tasks. However, they presented a lower SM than healthy controls.

Significance: This lower SM suggests that diabetics may present sensory impairment that could put them at risk of losing objects during its manipulation. Also, it suggests that the applied experimental procedure is sensitive to detect mild sensory impairment in diabetics.

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1. Introduction

Object manipulation could be considered as an essential functional motor action, critical for living an independent lifestyle. A successful object manipulation depends on the individual's ability to exert an adequate magnitude of grip force (GF – force component acting perpendicularly to the object surface) to prevent slippage caused by external and by self-generating forces acting tangentially (load force – LF) at the digits–object surface interaction. Consistent with a simple mechanical model, in order to hold an object, GF has to be at least equal to the ratio of LF and the static coefficient of friction (COF) acting upon the digits–object interaction (i.e., $GF = LF/COF$) (Johansson and Westling, 1984; Westling and Johansson, 1984). However, during manipulation individuals tend to be more conservative by adopting a safety margin (SM), that is, individuals apply slightly higher GF than the minimum needed to prevent slippage (GF_{min}). Also, GF is constantly modulated with respect to ongoing changes of LF providing a relatively low and stable surplus of GF above GF_{min} (Johansson and Birznieks, 2004; Johansson and Flanagan, 2008). This behavior has been observed in a variety of manipulation tasks, from holding in place to shaking a handheld object (de Freitas et al., 2009; Flanagan and Wing, 1995; Zatsiorsky et al., 2005).

It has been generally accepted that the skin mechanoreceptors provide information about object's weight and COF and allow for rapid and accurate estimation of the GF_{min}. Actually, this information is utilized for a quick adaptation of GF to the current object's physical properties and for updating the central controller about the events occurring at the digits–object surface interaction (Johansson and Birznieks, 2004; Johansson and Flanagan, 2008). It is already known that several neurological diseases alter the central nervous system's (CNS) ability to control and scale GF with respect to LF and COF. For example, mild affected multiple sclerosis patients apply much more GF than needed to lift and hold an object (i.e., elevated SM) (Iyengar et al., 2009; Krishnan et al., 2008; Marwaha et al., 2006). Also, individuals with cerebellar dysfunction (Muller and Dichgans, 1994; Nowak et al., 2002), stroke survivors (Hermsdorfer et al., 2003), individuals with Parkinson's and Huntington's disease (Fellows et al., 1998; Nowak and Hermsdorfer, 2002; Serrien et al., 2002), and individual with chronic somatosensory deafferentation (Hermsdorfer et al., 2008; Nowak et al., 2004) show an elevation of GF and, consequently, SM when compared with healthy individuals in different manipulation tasks. Surprisingly, there are no studies about GF control in diabetic individuals without and with diagnosis of diabetic peripheral sensory neuropathy (DPN).

According to the World Health Organization (1999) diabetes mellitus (DM) is a metabolic disorder caused by defects in insulin secretion, insulin action, or both, which directly affect the carbohydrate, fat and protein metabolism. The DM is characterized by chronic hyperglycemia, which, if persistent, can produce injury, loss of function, and failure of various body tissues and organs. The DM can also cause pathological and functional changes, including progressive development of retinopathy, nephropathy, and/or neuropathy. Around fifty percent (50%) of diabetic individuals show some type of neuropathy and the most common is the DPN. The DPN affects the sensory and motor neurons and is characterized by the reduction in nerve conduction velocity, decreased sensitivity in the distal end of upper and lower extremities, and by decreased motor function in more severe stages (Ramji et al., 2007; Watkins and Thomas, 1998). The DPN remains undetected in most of the cases and it is diagnosed only by sophisticated clinical and neurological tests (e.g., sensory and/or motor nerve conduction velocity and electromyography) or when more severe symptoms and complications caused by DPN progress. Symptoms like numbness and paresthesias are very common in persons with DPN, mainly in the feet and lower extremities, and they are related to functional deficits in the peripheral sensory system. However, despite the more severe consequences of the DPN is seen in the lower extremities (e.g., amputation), the hands are also affected by the deficits in sensory information (Dahlin et al., 2008).

As most of the diabetic individuals may have subclinical signs of DPN (e.g., sensory deficits) without presenting any clinical sign and functional loss (e.g., maximum power grip strength) (Meijer et al., 2008) and based upon results of previous studies showing that individuals with central and peripheral neurological deficits present changes in GF magnitude control during simple object manipulation (Krishnan et al., 2008; Nowak and Hermsdorfer, 2006), we believe that the GF magnitude could be a sensible performance variable to detect mild neurological deficits in diabetic individuals without formal diagnosis of DPN and, consequently, could be used as the first sign of neuropathy. Therefore, the aim of this study was to evaluate and compare hand function and GF control of diabetics without DPN and healthy controls. We hypothesize that while the tests traditionally used in clinical and research settings to assess hand function would not be sensible to detect differences between diabetic individuals without DPN and healthy individuals, the tests using instrumented handles, which provide accurate information about GF control would be able to detect such differences. Specifically, we expect that diabetic individuals should select a higher SM than healthy individuals due to slight sensory loss mainly from the sensors located at the tip of their digits.

2. Methods

2.1. Participants

Twelve diabetic individuals between 31 and 60 years-old (mean ± SD, 50.3 ± 10.6 years, BMI = 27.53 ± 3.22 kg m^{-2}) without medical diagnosis of DPN, and twelve healthy age- and gender-matched controls (49.9 ± 10.55 years-old, BMI = 26.96 ± 3.07 kg m^{-2}) volunteered to participate in the study. All participants were right-handed as indicated by their answers to the Edinburg Handedness Inventory (Oldfield, 1971). Prior to take part in the study the participants signed an informed consent form approved by the local Institutional Research Ethics Committee.

In order to be selected to participate, the diabetic individuals should not be older than 60 years, be following treatment prescribed by a physician, not have diagnosis of DPN, retinopathy, and nephropathy, should not present loss of protective cutaneous sensation in the foot assessed by Semmes–Weinstein Monofilaments Examination (SWME, monofilament ⩽10 g), and should have a score equal or lower than six in the questionnaire part of the Michigan Neuropathy Screening Instrument (Feldman et al., 1994; Valk et al., 1994). Both, diabetic individuals and healthy controls should be able to understand and follow simple instructions and have no history of musculoskeletal injury or disease affecting their hands (e.g., carpal tunnel syndrome) and upper-extremity functions.

2.2. Experimental procedure

2.2.1. Hand function assessment

The experimental procedure started with the examination of the cutaneous pressure sensitivity of feet (for screening purposes) and hands (i.e., tips of thumb, index and little fingers) using the SWME. After, the participants, comfortably seated in a chair, performed three tests traditionally used to evaluate hand function: Rolyan nine hole peg test (9HPT), Jebsen–Taylor hand function test (JTHFT) and maximum power grip strength (GS$_{Max}$). The tests were performed with the dominant and non-dominant hands. Half of the individuals and their respective controls started the tasks with their dominant while the other half started with their nondominant hand.

The 9HPT intends to assess digital dexterity and consists of catching and placing nine small cylindrical pegs in nine small holes, one at the time, until all nine holes are filled, followed by the immediate return of the pegs to their original container (Mathiowetz et al., 1985b). The participants were instructed to perform the task as quick as they could and verbal motivation was provided during the test execution. They repeated the test three times with each hand in an alternated way. The time to accomplish the task was measured by a stopwatch and the shortest time among the three trials was used as the dependent variable.

The JTHFT is a test designed to evaluate patient's hand function by assessing the performance in tasks (seven subtests) that resemble daily executed manipulation tasks (Jebsen et al., 1969). The seven subtests are [1] writing short sentences, [2] turning cards, [3] picking and transporting small objects, [4] simulated feeding, [5] stacking checkers, and [6] moving lightweight and [7] heavyweight cans. The first subtest (i.e., writing) was not performed due to the sentence being written in English Idiom and the participants were Portuguese native speakers. The participants were asked to perform the six subtests as fast as they could and the time of execu-