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Postural control following a self-initiated reaching task in type 2 diabetic patients and age-matched controls

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Abstract

Although the postural stability of diabetic patients is affected in the presence of polyneuropathy, it has been suggested that diabetes *per se* has no effect on balance control during quiet standing. However, recent studies have reported muscular mechanical deficits in patients with type 2 diabetes (T2D) that may be highlighted during a more destabilizing task than quiet standing. Therefore, the objective of this study was to compare non-diabetic and T2D subjects during a modified version of the functional reach (FR) test in order to discriminate differences in postural control associated with diabetes *per se*. Thirty subjects (15 non-diabetic and 15 T2D) were requested to stand on a force platform and to perform the FR test. Center of pressure velocity (V_{COP}), root-mean-square (RMS) amplitude and range of the COP were calculated in the anterior–posterior direction during three specific periods of the FR performance: namely ‘‘before’’, ‘‘on-going’’ and ‘‘after’’.

No significant difference between the non-diabetic subjects and the T2D subjects was found for the FR performance. However, T2D subjects had significantly higher V_{COP}, RMS and range of COP displacements for the ‘‘after’’ period compared to the non-diabetic group ($p < 0.05$).

These results suggest that T2D subjects without peripheral neuropathy may have difficulties regaining their stability after a self-initiated reaching task. Therefore, diabetes mellitus *per se*, could have a direct effect on postural control during standing after a self-induced forward reaching movement.

Keywords: Functional reach; Center of pressure; Posture; Dynamic balance; Diabetes

1. Introduction

According to the World Health Organization [1], the number of diabetic patients is going to increase by approximately 122% by 2025 to reach a total of 300 million individuals. A large part of them will develop type 2 diabetes (T2D) and will ignore their disease until neurological or physiological complications appear. While efforts have to be made in prevention and treatment of the disease, it will also be important to improve screening in order to take earlier charge of the functional impairments of the patients. The use of posturographic studies in association with clinical and functional tests could bring new insights since postural instability and falls are often reported in long-term diabetic patients [2–5].

Within 10 years after diagnosis, it is frequent to observe a distal symmetric primarily sensory polyneuropathy (PN) in the diabetic population in parallel, with a reduction of the nerve conduction velocity [5]. The degeneration of both the afferent sensory cues and efferent motor nerves leads to a greater sway during quiet standing tasks and a greater risk of falls [3,4,6]. However, these results seem not to be related to diabetes *per se*. For instance Simoneau et al. [4] reported no significant difference in quiet standing between diabetic

Abbreviations: FR, functional reach; COP, center of pressure; COM, center of mass; COP – COM, center of pressure minus center of mass; V_{COP}, center of pressure velocity

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patients without PN and control subjects. Furthermore, Di Nardo et al. [6] reached to the same conclusion when comparing control subjects with insulin-dependent diabetes mellitus patients (IDDM) without PN. Indeed, diabetic patients without PN showed no difference for the Sensory Organization Test compared to controls. This test includes six conditions during which the subject tries to maintain an upright stance with as less sway as possible. Taken together, these results suggest that either the postural control system is not affected in diabetes patients until PN appears or the quiet standing task is not sufficiently challenging to discriminate early degenerations of the postural control system in the diabetic population.

Some studies did report that neuromuscular components are affected in a diabetic population even without PN. Simoneau et al. [4] reported weaker ankle dorsiflexor and plantarflexor torques in diabetic patients without PN compared to a control group during a quiet standing task. More recently, Trevino et al. [7] showed a significant increase in stiffness for both dorsiflexors and plantarflexors muscles for the diabetic patients without foot ulcers and with normal cutaneous sensitivity compared to control subjects. Therefore, a more destabilizing task combined with posturographic analysis could highlight differences in control and diabetes patients without PN.

Postural control can be assessed in posturography using a force platform to quantify the postural sway [6,8]. The main biomechanical variable that has been studied is the center of pressure (COP) (see [9] and [10] for reviews). The COP represents the outcome of the inertial forces of the body and the restoring equilibrium forces of the postural control system [9]. In the recent years, several performance-based tests have been proposed to assess balance and functional mobility [11–16]. A clinical test frequently used is the functional reach (FR) test as described by Duncan et al. [15,17]. The FR measures the maximum distance an individual can reach forward at arm's length while keeping their base of support fixed. Thus, it measures the maximal safe standing forward reach, representing an approximation of the margin of stability [8,15,17]. FR test was then chosen in this study because of its very good metrologic quality (reliability and validity) to assess balance and the risk of falls [15,17]. During FR, the postural control system is challenged during a self-initiating movement (bending forward) causing the center of mass (COM) to approach the limit of the base of support. At this time, the margin of stability is reduced and large muscular torques have to be produced to counteract the gravitational torque. In this context, biomechanical factors associated with the FR task may demonstrate postural control impairments of the T2D patients.

The purpose of this study was to assess the postural control of community-dwelling non-diabetic subjects and patients with T2D but without diagnosis of PN in order to detect early signs of neuromuscular or proprioceptive degeneration associated with diabetes *per se*. Since the quiet standing task does not seem to discriminate changes in the postural control between T2D and control groups, we hypothesized that no significant difference would be observed between the two groups during the period of quiet standing posture (before FR). In contrast, we expected that a greater postural sway would be present in T2D patients compared to the control group during and after the dynamic phases since stiffness and some neuromuscular components are affected in T2D subjects even without PN.

2. Materials and methods

A total of thirty subjects (15 controls and 15 T2D patients) participated in this study. Group characteristics are presented in Table 1. All participants gave their written consent and the project was approved by the Research Ethics Committee of the University of Montreal and CLSC Côte-des-Neiges.

All diabetic subjects were seen by a physician and were diagnosed with diabetes mellitus. Furthermore, to take part in the present study, T2D patients had to control their glycemia within normal limits. They were recruited from the CLSC Côte-des-Neiges and a medical clinic. Peripheral sensory deficit was assessed with the 20-g monofilaments Semmes–Weinstein applied to four plantar sites [18,19,20]. Smieja et al. [21] found that the third and fifth toes and the head of the first and third metatarsi showed a sensibility of 94% to detect patient with sensory neuropathy. Semmes–Weinstein monofilaments of increasing diameter were pressed perpendicularly against the plantar surface aspect of each plantar site until the bending of the monofilament to determine the sensory threshold for each foot. Values greater than 3.61 g (200 mg level, blue) were indicative of sensibility abnormality [22]. Non-diabetic subjects were

Table 1
Group characteristics

Variables	Non-diabetic subjects ($N = 15$)	Diabetic subjects without PN ($N = 15$)	p
Gender (F/M)	12/3	11/4	0.67
Age (years)	53 ± 11	53 ± 8	0.91
Weight (kg)	78.0 ± 17.1	96.6 ± 22.5	0.01
Height (m)	1.57 ± 0.09	1.63 ± 0.07	0.06
Diabetes diagnostic (years)	–	4.8 ± 4.5	–
Semmes–Weinstein monofilaments (g)	3.3 ± 0.3	3.4 ± 0.2	0.55

Mean ± 1S.D.

selected from the CLSC Côte-des-Neiges and a medical clinic and were free from diabetes mellitus.

All participants were asked to stand as still as possible with eyes open and feet at shoulder width on an AMTI force plate (Advance Mechanical Technology Inc., MA, USA). They were requested to raise their right arm at shoulder height prior to the beginning of the trial. After 15 s of quiet standing, they were asked to achieve the maximal FR at natural speed (3 s for the entire movement) and to maintain that position until the end of the 30 s trial. To limit the variability of movement velocity, subjects performed a modified version of the FR. Indeed, a velocity range was suggested by the experimenter while demonstrating the movement with his own arm. Preliminary trials were made to ensure subjects performed the task correctly. Moreover, to be accepted, the movement had to be performed with a trunk bending without flexing the knee joints. A maximum of four preliminary trials were made to ensure that the subjects performed the task correctly. When the subjects failed to perform the task, the trial was performed and recorded again. FR was evaluated with a 1-m measuring device besides their raised arm. Ground reaction forces and moments were collected during two trials at a sampling frequency of 20 Hz. The time-history of the COP profiles were calculated from the orthogonal forces and moments recorded by the force plate. The FR performance (cm), the mean V_{COP} (mm/s), the root-mean-square (RMS) amplitude (mm) and the range of the COP (mm) in the anterior–posterior (A/P) direction were used as dependent variables. These measures have been shown to have excellent reliability in quiet standing [9,15,23–25] and especially the V_{COP} [24,25]. V_{COP} was calculated by using instantaneous velocity and averaged on the duration of the phase. Furthermore, Lafond et al. [24] demonstrate that for V_{COP} two trials of 30 s were reliable to evaluate postural steadiness. To assure that the task was performed at the same velocity, we first calculated the horizontal acceleration of the COM from the ground reaction forces, according to the general equation of the dynamic

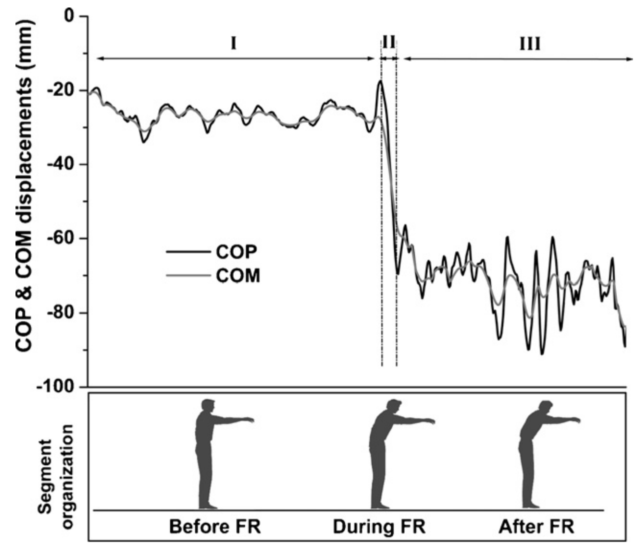

Fig. 1. Determination of the beginning and the end of the functional reach task by the utilization of the maximum and the minimum of the difference between COP and COM in mm. Phase I: "before", phase II: "on-going" and phase III: "after" the functional reach task.

($\sum \vec{F} = m\vec{a}$). Then, we integrated this acceleration to obtain the horizontal velocity of the COM.

To compare the effects of dynamic versus quasi-static phases of the task execution on postural control, we divided the FR performance in three different phases [26]. First, the period prior to the FR was named "before" and corresponds to a quasi-static phase. The second phase, the reach *per se*, which is the period of the dynamic instability, was named "on-going". Finally, the recovery phase was named "after" and corresponds to the period where the postural control system is trying to regain stability. The beginning of this phase also coincides with the end of the excursion of the arm. To obtain the beginning and the end of the 'on-going" phase, we first calculated the COM displacement from the "zero-point-to-zero-point integration technique" [27,28] and then determined the

Table 2

	Non-diabetic subjects ($N = 15$)	Diabetic subjects without PN ($N = 15$)	p
Functional reach (cm)	28.9 ± 4.8	28.6 ± 4.4	0.84
V_{COP} (mm s^{-1})			
Before	3.4 ± 1.3	4.6 ± 3.0	0.08
On-going	19.9 ± 4.1	21.7 ± 5.6	0.17
After	4.7 ± 1.1	8.0 ± 2.6	0.001
COP amplitude RMS (mm)			
Before	4.1 ± 1.4	5.6 ± 3.5	0.06
On-going	23.0 ± 4.8	25.2 ± 6.2	0.14
After	5.9 ± 1.3	10.2 ± 3.3	0.001
COP range amplitude (mm)			
Before	17.8 ± 5.2	27.6 ± 18.6	0.03
On-going	74.2 ± 0.27	85.7 ± 19.9	0.04
After	29.0 ± 5.9	47.6 ± 12.5	0.001

Functional reach distance (cm), V_{COP} (mm s^{-1}), COP amplitude RMS (mm) and COP range amplitude (mm) for non-diabetic subjects and diabetic subjects without PN. Mean ± 1S.D.

two first maxima COP − COM amplitudes (Fig. 1). A one-tail Student's t-test was used to compare groups for the FR distance, the V_{COP}, the COP amplitude RMS and the COP range variables. Statistical significance was set at $p < 0.05$.

3. Results

No significant difference was observed between the diabetic and the control group in the task execution. The horizontal velocity of the COM obtained from the integration of forceplate data was not significantly different for both groups (non-diabetic subjects: 0.82 ± 0.46 m s^{-1} and T2D subjects: 1.01 ± 0.51 m s^{-1}) and no significant difference was found between the non-diabetic subjects (28.9 ± 4.8 cm) and the T2D subjects (28.6 ± 4.4 cm) for the FR performance. Moreover, the V_{COP} during the "before" and "on-going" phases of the FR task in the A/P direction were also no significantly different between both groups (Table 2). Nevertheless, a significant difference ($p < 0.05$) for the V_{COP} "after" the FR task was noticed between the diabetic (8.0 ± 2.6 mm s^{-1}) and the control group (4.7 ± 1.1 mm s^{-1}) in the A/P direction (Table 2). Table 2 also shows no significant difference between the COP amplitude for the "before" and "on-going" phases, but a COP amplitude significantly ($p < 0.05$) increased in the diabetic (10.2 ± 3.3 mm) compared to the control group (5.9 ± 1.3 mm) in the "after" phase in the A/P direction. For the COP range, in the A/P direction, we found significant differences for the "before", "on-going" and "after" phases with larger COP ranges for the T2D group compared to the control group (see Table 2).

Since the weight of both groups was significantly different (Table 1), coefficients of correlation between the COP velocity and the weight of the subjects were performed during the "on-going" and the "after" periods of the movement. Results showed that the difference in weight of the subjects did not influence the COP velocity during the "on-going" and the "after" periods of the execution of the FR ($r = 0.28$ and 0.22, respectively, Fig. 2). Similar results were observed for both COP range ($r = 0.24$ and 0.26) and COP amplitude RMS ($r = 0.25$ and 0.21) during the "on-going" and the "after" periods. Furthermore, no effect of gender on the results was observed in this study.

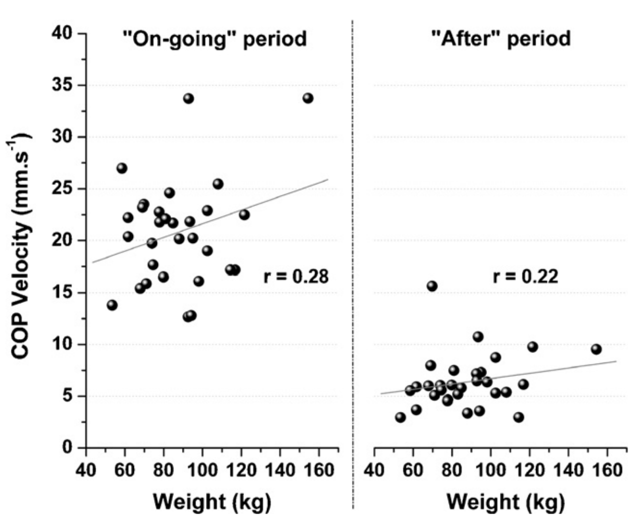

Fig. 2. Correlations between the COP velocity and the weight of the subjects for the "on-going" and "after" periods.

4. Discussion

The purpose of this study was to assess the postural control during a dynamic task in community-dwelling non-diabetic subjects and subjects with T2D but without diagnosis of PN in order to detect early signs of functional impairments in diabetes patients.

4.1. Task execution

Despite significant differences for the period following the execution of the movement, the FR task does not seem to be difficult to perform for T2D patients without PN. Indeed, no subject failed to execute the task and they all reached a distance similar to the control group. Otherwise the dynamic of the movement seemed to be similar. Ferry et al. [29] reported that the accelerations of the body segments are related to the COP displacements. Therefore, in our study, since no significant difference was found in the horizontal acceleration during the completion of the movement, we believe that the task was performed at the same velocity for both groups.

4.2. Postural control in T2D patients

Our results report significant differences for only one postural parameter (COP range) during the quiet standing period between both groups. This finding might suggest that postural assessment during quiet standing could discriminate T2D patient without PN from control subjects. These results differ from Simoneau et al. [4] and Di Nardo et al. [6] who did not find any difference between T2D patients without PN and non-diabetic subjects during a quiet standing task. However, in the present study, no significant differences were also found between T2D patients and non-diabetic subjects during the quiet standing ("before") period for two out of three variables including the COP velocity. This latter postural parameter has been recognized as the most reliable for quiet standing assessments [24]. Therefore, the conclusion suggested by Simoneau et al. [4] and Di Nardo et al. [6] is probably true for a quiet standing task. Nevertheless, when considering a task that required stronger and more complex neuromuscular activation, the present study showed a significant effect of diabetes without PN on postural control for all biomechanical variables.

In the "after" period our results show that the T2D subjects are more destabilized than the non-diabetic group.

These results suggest that T2D subjects, without PN, have difficulties to compensate the postural unbalance and to maintain the final trunk position. Therefore, our results suggest that the T2D subjects have a worst postural control compared to healthy subjects especially when they try to regain balance ''after'' a self-initiated perturbation. Furthermore, this study shows that diabetes *per se* may affects the dynamic postural control in T2D patients without a diagnosis of PN.

4.3. Causes of postural unbalance in T2D

Decades of research in postural control provide many insights that the postural control system involves sensory integration instead of just eliciting reflex responses [30–32]. Postural instability in diabetic PN patients is usually attributed to the lack of accurate proprioceptive feedback (sensory ataxia) from the lower limbs [3,4,33]. During quiet standing, numerous studies have reported that diabetic patients with PN showed larger V_{COP} [3,34,35] and larger COP range [3]. High correlations were also found between the severity of the PN and COP measures (COP excursion and V_{COP}) [4,15,34]. In our study, the subjects were not diagnosed with PN but the results obtained in the ''after'' period are in accordance with these later studies suggesting that the FR test associated with posturographic analysis can detect the early signs of functional impairment in diabetes patients. The perturbation created during the FR and the maintenance of that forward trunk position definitely challenged the postural system and may solicit more the afferent sensory input from proprioceptors.

During the ''after'' phase, the COP is restricted in a small forefoot area since the subjects are close to their stability limit. This position creates a large gravitational torque that has to be compensated by an equal muscular torque at the ankle and hip joints. Therefore, our results may also suggest that neural and/or mechanical properties around the ankle joint might be affected in diabetes patients while no sensory PN is diagnosed yet. This hypothesis is supported by Simoneau et al. [4], who reported weaker ankle dorsiflexor and plantarflexor muscular torques in T2D patients without PN compared to non-diabetic subjects. Two reasons might explain this decrease in ankle torques in T2D patients. The weaker torques can be attributable to stiffness or to neuromuscular deficits. The study by Salsich et al. [36] reported no significant difference between T2D patients with NP compared to controls in passive stiffness. This suggests that passive stiffness deficit is not responsible for plantarflexor weakness. Moreover, although our modified version of the FR is a destabilizing task, it does not involved large angular amplitude at the ankle joint which rules out an implication of passive stiffness [7,36]. Therefore, our results might be explained by neuromuscular deficits.

4.4. Adequacy of postural analysis during the functional reach test

The FR test is a reliable and valid measure of postural stability [13,37], has a predictive validity of falls and discriminates fallers from non-fallers [37,38]. The use of a quantitative and non-invasive technique, such as computerized dynamic posturography, during a self-initiated reaching task may help to discriminate early stages of functional problems related to diabetes *per se*. Although, even the results of FR performance and COP postural steadiness measures did not put diabetes patients at risk of fall, the postural analysis reveals that they have more difficulty to maintain balance after a self-induced forward reaching movement, possibly due to mechanical deficits. Dynamic posturography may provide insights for early clinical interventions specifically designed for the prevention of fall.

The limitations of the present study are mainly related to the characterisation of the subjects' diabetic history**.** The T2D patients were followed by a physician, assuring us that sugar blood levels were within normal range. Further studies including nerve conduction velocity assessments should be conducted to provide a more accurate PN diagnosis.

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