Clinical Biomechanics 32 (2016) 236–240

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Muscle activation patterns related to diabetic neuropathy in elderly subjects: A Functional Reach Test study

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ARTICLE INFO

Article history:
Received 25 May 2015
Accepted 17 November 2015

Keywords:
Surface EMG
Functional Reach Test
Healthy elderly
Diabetes
Balance disorders

ABSTRACT

Background: This study was designed to assess, in healthy elderly, non-neuropathic and neuropathic diabetic subjects, the activation patterns of the main muscles involved in the Functional Reach Test, a well-recognized method to identify elderly subjects at risk of balance impairments.
Methods: Surface electromyographic analysis of Sternocleidomastoideus, Rectus Abdominis, Erectores Spinae at L4 level, Rectus Femoris, Hamstrings, Tibialis Anterior and Soleus was performed in 10 healthy, 10 diabetic non-neuropathic and 10 diabetic neuropathic subjects.
Findings: Results showed that in every group the first motor is Tibialis Anterior, that is recruited before the start of the test. An earlier activation of Tibialis Anterior ($P < 0.05$) was detected in diabetic neuropathic (ON at −24% of the test period), compared with healthy (−11%) and diabetic non-neuropathic (−13%) groups. A significant earlier activation of Sternocleidomastoideus and Rectus Abdominis was found in diabetic neuropathic group, only with respect to healthy subjects. No significant difference was found in Rectus Femoris, Soleus, Hamstrings an Erectores Spinae onset among the three groups.
Interpretation: Results suggest a trend of diabetic neuropathic patients in earlier anticipation of the activation of the anterior body-muscles. In particular, the earlier onset of Tibialis Anterior is likely to be performed to adjust the movement timing and to compensate for the delay in the recruitment of the motor units. This anticipation might be involved in the altered postural control with increased balance impairment detected in diabetic neuropathic patients, and thereby it might also be proposed as an index of neuropathy, evidenced in a simple and non-invasive manner.

1. Introduction

The World Health Organization warns that currently 347 million people worldwide suffer diabetes and approximately 15% are likely to develop nerve disorders such as peripheral neuropathy (PN). Peripheral neuropathic patients exhibit decreased stability while standing (Fioretti et al., 2010; Simoneau et al., 2004) as well as during dynamic conditions (Agostini et al., 2012; Bloem et al., 2000; Inglis et al., 1994). In these patients, abnormalities in the myoelectric activity of subjects with PN due to peripheral sensory deficit are reported (Reeves and Swenson, 2008; Sawacha et al., 2012), together with a high incidence of injuries and a low level of perceived safety with consequent increase of fall risk (Cavanagh et al., 1992; Maurer et al., 2005).

Balance impairment and falls are a leading cause of disability, injury and death in elderly people and represent a major public health problem with substantial medical and economic consequences. To assess the fall, several studies have focused on balance and gait performance, involving both the anterior–posterior (AP) and the medio-lateral (ML) plane of motion. Johnson Hilliard et al. (2008) reported that measures of ML postural sway have been associated with recurrent falls and future risk of falls. Among reaching test in the AP direction, the Functional Reach Test developed by Duncan et al. (1990) was proposed as a measure of balance able to identify elderly subjects at risk of recurrent falls. Functional Reach (FR) was defined as the maximum distance one can reach forward beyond arm's length, while maintaining a fixed base of support in the standing position. It is a simple, fast, and clinically validated test (Duncan et al., 1990, 1992) and is based on the idea that the maximum, voluntary, inclined posture can be used to investigate limits of stability in the absence of external perturbations. However, the information provided by the FR maximum distance alone does not seem to be adequate for the identification of balance impairments (Wernick-Robinson et al., 1999). For this reason, recently Maranesi et al. (2014) proposed to evaluate the possibility of balance impairment by the use of kinematic and kinetic analysis of FR-test data. This study was performed in neuropathic diabetic patients (compared with non-neuropathic diabetic patients), since peripheral neuropathy is widely recognized as a cause of balance disorders. This study, however, did

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http://dx.doi.org/10.1016/j.clinbiomech.2015.11.005
0268-0033/

not include the myoelectric analysis of muscle activity during the execution of this motor task, rather used during other motor tasks, such as locomotion (Di Nardo et al., 2015a,b; Perry, 1992) or trunk bending and reaching movements (Crenna et al., 1987; Farahpour et al., 2015; Oddsson and Thorstensson, 1986; Stapley et al., 1998; Tyler and Karst, 2004). In particular, surface electromyography (sEMG) during test with voluntary postural perturbation was used for the analysis of forward and backward trunk bending and bilateral reaching movements, and not during the FR test and, in particular, not in diabetic and diabetic neuropathic subjects.

This study is aimed at assessing the activation patterns of the main muscles involved in the FR test in healthy elderly subjects, non-neuropathic diabetic, and neuropathic diabetic patients, in order to evaluate the balance disorders with the presence of diabetes and neuropathy.

2. Methods

2.1. Subjects

The FR test was performed in 30 elderly age-matched subjects divided into three categories: 10 healthy subjects (CTRL), and 20 diabetic patients affected by type-2-diabetes mellitus, 10 diabetic non-neuropathic patients (D), and 10 diabetic symptomatic neuropathic patients (DN). Their clinical data are shown in Table 1. Exclusion criteria, to select the healthy elderly subjects, included history of neurological disorders, orthopedic surgery, acute/chronic knee pain or pathology, abnormal gait and/or Functional Ambulation Profile (FAP) Score ≤ 95. The FAP scoring system, developed by Nelson (1994), provides a quantitative means of assessing gait without the subjective qualification that most rating scales require. Diabetic neuropathy in DN was diagnosed by nerve conduction studies performed by electromyography according to the criteria described by the American Diabetes Association (1992). Other potential causes of PN, such as neurotoxic medications, alcohol abuse, vitamin B_{12} deficiency, renal disease, chronic inflammatory demyelinating neuropathy and vasculitis, were excluded on the basis of patients' history, laboratory examinations, and electromyographic patterns. All DN patients were symptomatic. The presence of neuropathic symptoms was assessed by the Diabetic Neuropathy Symptom score, which was considered to be positive with a score of 1 or higher as described by Meijer et al. (2003). All subjects gave their informed consent prior to testing.

2.2. Experimental protocol

The measurement protocol consisted in standing barefoot on a dynamometric platform (Kistler, 9281 type, sample rate 480 Hz). The dominant arm was extended and kept perpendicular to the trunk. The test consisted in moving the dominant arm as far forward as possible, and immediately backward again maintaining the wrist along a yardstick positioned at shoulder height. The test was performed at the maximum possible speed in order to have more repeatability (Kozak et al., 2003). The FR test was repeated three times by each subject, according to literature (Duncan et al., 1990).

Table 1
Mean (standard deviation) of anthropometric data of the three groups (CTRL, D and DN).

	CTRL	D	DN
Age [years]	73.5 (5.1)	72.6 (4.1)	72.1 (5.0)
Height [cm]	160.3 (7.4)	162.2 (10.7)	171.3 (6.2)
Mass [Kg]	70 (16.6)	80 (11.9)	81.7 (12.7)
Body mass index [$kg \cdot m^{-2}$]	27.1 (5.5)	30.3 (2.9)	27.7 (3.2)
Foot length [cm]	25.5 (1.2)	25.5 (1.3)	26.6 (1.0)

CTRL = healthy elderly subjects; D = diabetic non-neuropathic subjects; DN = diabetic neuropathic subjects.

Kinematics was acquired by a 6-camera Elite optoelectronic system (BTS SMART D, sample rate 120 Hz). Passive markers were placed according to the protocol described in Davis et al. (1991) with an additional marker placed on the dominant wrist. sEMG signals were acquired using a wireless 8-channel sEMG system (BTS FREE EMG 300, sample rate 1000 Hz, resolution: 16 bit). sEMG signals were detected with single-differential sEMG probes with variable geometry constituted by Ag/Ag–Cl disks (size: 17 × 36 × 8 mm; weight < 9 gr; interelectrode distance: 16 mm, high–pass filter: 10 Hz, input impedance > 10 GΩ, CMR > 110 dB, sensitivity < 1 μV). sEMG probes were attached unilaterally (dominant side) over Sternocleidomastoideus (Scm), Rectus Abdominis (RAbd), Erectores Spinae at L4 level (L4), Rectus Femoris (RF), Hamstrings (Ham), Tibialis Anterior (TA) and Soleus (Sol) following the SENIAM recommendations (Freriks et al., 2000). An overall gain, ranging from 1000 to 50000, can be chosen to suit the need of the specific muscle observed

2.3. Definition of parameters

FR distance was defined as the difference between the point of maximum forward extension of the wrist from its initial starting position; it was normalized to the subject's height (FR_H). To verify the initial position of each subject, the angle of the lower limb with respect to the vertical axis (initial angle), was computed and reported in Table 2 together with the kinematic parameters computed as described in Maranesi et al. (2014). A positive value for initial angle indicates an initial ankle dorsiflexion.

2.4. Data analysis

FR-start instant was defined as the point in time immediately preceding the initial backward path of center of pressure (CoP) excursion necessary to initiate trunk flexion. FR-end instant was defined as the first time instant when the subject's wrist speed reaches zero, once the maximal speed was attained. All parameters were computed relatively to this time interval. The time interval was normalized with respect to the FR-period.

All kinematic data were filtered by a 4th order low-pass Butterworth filter at a 5 Hz cut-off frequency. The sEMG signals were full-wave rectified and band-pass filtered (Butterworth, 10–450 Hz). The root mean square value of each sEMG signal was computed and then processed by a double-threshold detector that provides the onset and offset time instants of muscle activity. This technique (De Luca, 1997) consists of selecting a first amplitude threshold for the signal and identifying the sample when the signal exceeds this threshold and remains above it for at least 50 ms (this interval represents the second temporal threshold); this sample is acknowledged as the ON-instant of the muscle activity. In the same way, the first sample after the ON-instant, from which the signal remains below the first threshold for at least 50 ms, is acknowledged as the OFF-instant. The setting of the first threshold is based on the assessment of the background noise level, acquired in

Table 2
Mean value (standard deviation) of reach time, FR_H, initial_angle, hip flexion, ankle plantarflexion, trunk rotation angles and results of the statistical analysis of differences for three groups (CTRL, D and DN). Positive values for initial_angle indicate an initial ankle dorsiflexion, i.e. an initial forward shank inclination.

	CTRL	D	DN
Reach time [s]	0.74 (0.09)	0.87 (0.11)	0.75 (0.12)
FR_H	0.16 (0.03)	0.14 (0.03)	0.11 (0.03)*
Initial_angle [deg]	5.3 (2.6)	5.0 (3.3)	6.0 (3.9)
Hip flexion [deg]	25.4 (6.7)	26.0 (6.8)	24.8 (7.9)
Ankle plantarflexion [deg]	7.0 (2.8)	10.1 (7.2)	8.9 (4.6)
Trunk rotation [deg]	9.6 (3.4)	7.9 (4.2)	10.4 (4.6)

CTRL = healthy elderly subjects; D = diabetic non-neuropathic subjects; DN = diabetic neuropathic subjects; FR_H = FR distance normalized to the subject's height.
* $P \leq 0.05$ between CTRL and DN groups.