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Functional reach test: Movement strategies in diabetic subjects

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ABSTRACT

Functional reach (FR) is a clinical measure, defined as the maximum distance one can reach, forward beyond arm's length, able to identify elderly subjects at risk of recurrent falls. Subjects, exhibiting the same FR can perform the motor task in different ways: a kinematic analysis of the FR, task can help to identify the motor strategy adopted. The FR test was applied to 17 diabetic non-neuropathic, (CTRL) and 37 neuropathic (DN) subjects. Motor strategies adopted were defined as: "hip" or "other" strategy; the latter included: "mixed" and "trunk rotation" strategies. Principal Component Analysis and non-parametric statistical tests were used to study the different execution modalities of the FR test. Results show that, in CTRL, the most important parameters are those related to trunk flexion in the sagittal plane. Instead, for DN, the main features are related not only to trunk flexion but also to trunk rotation in the transverse plane. Percentages of subjects who used "hip" or "other" strategies are similar for CTRL and DN subjects. However, within the "other" strategy group, the percentage of DN that used a "trunk rotation" strategy was much higher than for CTRL. Results show that individuals, although exhibiting the same reaching distance, adopt different movement strategies. Consequently it is important to evaluate the kinematic behaviour and not only the clinical measure, because the evaluation of the motor strategy might be useful in the early detection of subjects at risk of postural instability.

1. Introduction

The functional reach test developed by Duncan et al. [1] has been proposed as a measure of balance able to identify elderly subjects at risk of recurrent falls. Functional reach (FR) has been 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 based on the idea that to investigate limits of stability in the absence of external perturbations, the maximum, voluntary, inclined posture can be used. In fact, limits of stability, quantified by the maximum, intentional displacement of the body in a given direction without losing balance, are influenced by body biomechanics as well as by subjective perception, and internal postural control abilities [2]. Therefore, a greater reach distance indicates a larger limit of stability and hence a better ability to maintain stability while moving during a standing position [3]. In particular Duncan et al. [4] concluded that a reach distance smaller than 152 mm is strongly correlated with high fall risk in individuals aged 70 years or older.

FR is clinically measured using a yardstick secured to the wall at the height of the shoulder, and it is a simple, fast, and clinically well accepted test. It has been demonstrated to be precise, portable, inexpensive and reliable [1]. It can be used as a marker of physical frailty [5], and as a useful measure for patients following a stroke [6], with vestibular dysfunction [7], and Parkinson's disease [8]. Furthermore, Fioretti et al. [9] show how the analysis of static posture performed on diabetic subjects with and without neuropathy is able to underline differences between the two categories of patients. Hence, it was thought that a postural test with voluntary perturbation may highlight differences between the two groups of patients. In fact, the diabetic neuropathic subjects exhibit a reduction in tactile and proprioceptive sensitivity [10] and therefore a high risk of fall compared with non-neuropathic patients [11,12]. Age, height and execution speed influence FR. In fact, differences in height and age rather than gender contribute to a shorter reach distance [1]. Regarding speed, it has been noticed that movements at maximum speed are more repeatable [13,14].

As shown in Wernick-Robinson et al. [15], the clinical FR measure is not able to differentiate between healthy elderly people and individuals with balance impairments. Further information can be obtained from this motor task by looking in more detail at the kinematic behaviour [16] and also at the movement strategies

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employed [17–19]: in fact, it has been noted that different strategies, such as the hip or ankle strategy, trunk rotation in the transverse plane and total body flexion similar to a squat, are used to accomplish this motor task [15].

The aims of this study were to identify the parameters that characterise the FR test in non-neuropathic and neuropathic diabetic subjects, and to check the relationship between the FR clinical measure (normalised with respect to subject height) and other parameters describing the body movement during the motor task. Furthermore, the presence of different strategies used by these two classes of subjects was also investigated.

2. Materials and methods

The FR test was applied to 54 patients affected by type-2-diabetes mellitus: 17 diabetic non-neuropathic subjects (CTRL, 11 females, 6 males, 68.5 ± 3 years old) and 37 diabetic neuropathic subjects (DN, 8 females, 29 males, 60 ± 11 years old). The mean values of their height, foot length, and body mass index were, for the CTRL group 162.5 ± 10.5 cm, 25.8 ± 1.1 cm and 28.4 ± 4.3 kg/m^2, respectively, while for the DN subjects 167.5 ± 9.5 cm, 26.3 ± 1.7 cm, and 28.6 ± 4.9 kg/m^2 respectively. Diabetic neuropathy was diagnosed by nerve conduction studies performed using electromyography according to the criteria described by the American Diabetes Association [20]. Other potential causes of peripheral neuropathy, 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. The absence of neuropathy in CTRL subjects was assessed by electromyography. 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. [21]. The level of glycosylated haemoglobin was 7.1 ± 0.8% for the CTRL subjects, and 7.7 ± 1.1% for the DN patients.

The study was approved by the Ethic Committee of the INRCA Hospital (process No.124/2006) and all subjects gave their informed consent prior to testing.

The measurement protocol consisted in standing barefoot on a dynamometric platform (Kistler 9281 type) sampled at 100 Hz. The dominant arm was extended and kept perpendicular with respect to the trunk. The test consisted in moving the dominant arm as far forward as possible and immediately backward again. The test was performed at the maximum possible speed in order to have more repeatability of parameters [16]. Each subject was instructed "to move the dominant arm as far as possible and to come back maintaining the wrist above the yardstick"; the latter was positioned at shoulder height and parallel to the floor. Each subject performed three training trials to acquire familiarity with the test.

Kinematics was acquired by a 6-camera Elite optoelectronic system (BTS, sampling rate 50 Hz). Twenty-six passive markers were placed on the various anatomical landmarks described in Table 1.

The FR distance was defined as the difference between the point of maximum forward extension of the wrist from its initial starting position, and was normalised to the subject's height (FR_H). The FR-start instant was defined as the point in time immediately preceding the negative peak of centre of pressure (COP) excursion. The end of movement was defined as the first time instant when the subject's wrist speed reached zero after the start. All the parameters were computed relative to this time interval. All the kinematic data were filtered by a 4-th order low-pass Butterworth filter with a 5 Hz cut-off frequency.

Table 1
Marker locations and acronym description (r = right; l = left).

Acronym	Description
MALLr,l	Lateral malleolus
METr,l	Second metatarsal head
HEELr,l	Heel
HFr,l	Head of fibula
FEr,l	Femur lateral epicondyle
GTr,l	Greater trochanter
ICr,l	Iliac crest
ASISr,l	Anterior superior iliac spina
PSISr,l	Posterior superior iliac spina
T12-L1r,l	Space between the twelfth thoracic vertebra and the first lumbar vertebra
ACROMr,l	Shoulder acromion
TRAGr,l	Tragus
C7	Seventh cervical vertebra
WRIST	Ulnar styloid process of the dominant wrist

The centre of gravity (COG) was defined as the projection of the whole body centre of mass (COM) on the force platform; COM was estimated referring to a 14-segment model and to Winter's anthropometric data [22]. Eighteen parameters were computed: 12 kinematic parameters, using landmark position data and 6 stabilometric parameters, 4 using COP displacement data and 2 estimating the COG displacement. Their definition is given in Table 2. Although some of them refer to literature [16,23,24], others were also added (Table 2). In particular, trunk rotation was computed in five different ways: three by angles defined in the transverse plane and two by angles between segments defined in the 3D space. The Mann–Whitney *U* test was applied to test statistically significant differences ($p < 0.05$) between CTRL and DN parameter mean values.

The kinematic strategies used during the motor task were defined as follows [15]:

- "hip" strategy: hip flexion greater than 20 deg and ankle plantarflexion less than 5 deg;
- "other" strategy that included:
- "mixed" strategy: hip flexion less than 20 deg and ankle plantarflexion greater than 5 deg;
- "trunk rotation" strategy: trunk rotation in the transverse plane greater than 20 deg.

Principal component analysis (PCA) was used to select the most significant features among the set of kinematic and stabilometric parameters. PCA was applied to the complete parameter dataset considering both CTRL and DN subjects in a unique dataset. The minimum number of principal components (*PCs*) considered significant was determined using the Kaiser criterion. Varimax rotation was performed to obtain, for each PC, a group of homogeneous and significant variables. For each component, significant parameters were considered those exhibiting a loading value higher than 0.40, in absolute value [25,26]. For each subject, the component score, rather than individual parameters, was used to test statistically significant differences ($p < 0.05$) between the CTRL and DN groups. The Mann–Whitney *U* test was applied for this purpose.

Finally, Spearman's rank correlation coefficient was used to test the association between FR_H and the other parameters and to identify which of these had the greatest influence on reach distance. The correlation was assumed statistically significant at a p-value lower than 0.05.

MatLab software was used to compute all the parameters and to perform the statistical analysis.