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Extended summary

KINEMATIC, DYNAMIC AND ELECTROMYOGRAPHIC ANALYSIS OF FUNCTIONAL REACH IN DIABETIC SUBJECTS

Curriculum: Elettromagnetismo e Bioingegneria

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Abstract. A description of kinematic, dynamic and electromyographic features that characterise the Functional Reach (FR) Test in non-neuropathic and neuropathic diabetic subjects was proposed. The study is composed of two parts: the first one is focused on the description of the principal kinematic parameters that characterise this motor task and on the investigation of the motor strategies used during the test. The second one deals with the electromyographic analysis of specific body muscles in order to understand their timing during the execution of the FR Test. Results highlight how similar FR values can be obtained by different movement strategies. While for diabetic non-neuropathic subjects, FR is mainly performed by trunk flexion in the sagittal plane, for diabetic neuropathic patients, FR is also significantly accomplished by trunk rotation in the horizontal plane. From the electromyographic analysis, neuropathic and non-neuropathic diabetic subjects show a similar behaviour, with the anticipatory activity of tibialis anterior, necessary to move the centre of pressure backward and to give rise to the ankle dorsi-flexor moment able to unbalance the body forward. The difference is in the timing of this muscle activation: in fact, in diabetic neuropathic patients, the tibilias anterior is activated earlier than its activation in non-neuropathic subjects. So, the evaluation of the motor strategy and the electromyographic analysis of several trunk, thigh and shank muscles, in addition to the clinical FR measure, might be useful in the early detection of the subjects at risk of postural instability.

Keywords: Diabetic neuropathy, Dynamic analysis, Functional Reach Test, Kinematic analysis, SEMG analysis.

1 Problem statement and objectives

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 maximal 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. As shown in [2], the clinical FR measure cannot be considered as a measure of dynamic balance because it is not able to differentiate between healthy elderly people and individuals with balance impairments. More information can be obtained from this motor task by looking in more detail at the kinematic behavior [3], at the motor strategies employed and also at the electromyographic activity pattern.
The study is composed of two parts: the first one is focused on the description of the principal kinematic parameters that characterise this motor task and on the investigation of the motor strategies used during the test. The second one is carried out in the surface electromyographic (SEMG) analysis of specific body muscles in order to understand the timing of muscle activity during the Functional Reach Test. The study has been conducted on non-neuropathic and neuropathic diabetic subjects.

2 Research planning and activities

For the first part of the study, the FR test was applied to 54 patients affected by type-2-diabetes mellitus: 17 diabetic non-neuropathic subjects (CTRL, 11 females and 6 males, 68.5 years old, SD 3) and 37 diabetic neuropathic subjects (DN, 8 females and 29 males, 60 years old, SD 11). The measurement protocol consisted in standing barefoot on a dynamometric platform (Kistler 9281 type) and moving the dominant arm as far forward as possible, whilst maintaining the level of the wrist above a yardstick, positioned at shoulder height and parallel to the floor. Kinematics was acquired by a 6-camera Elite optoelectronic system (BTS, sampling rate of 50 Hz). Twenty-six passive markers were placed on the various anatomical landmarks. Eighteen parameters were computed in total: 12 using markers placed on the anatomical landmarks (kinematic parameters) and 6 using centre of pressure or centre of gravity displacement data (stabilometric parameters). The kinematic strategies used during the motor task were defined as follows [2]: *hip* strategy, characterised by a minimum of 20 deg of hip flexion and 5 deg of ankle plantarflexion; *other* strategy that included: *mixed* strategy characterised by a hip flexion less than 20 deg and ankle plantarflexion greater than 5 deg; *trunk rotation* strategy characterized by a trunk rotation in the transverse plane greater than 20 deg. Principal Component Analysis and non-parametric statistical tests were used to study the different execution modalities of the FR test.
For the second part of the study, the test was applied to 10 diabetic patients affected by type-2-diabetes mellitus: 5 diabetic non-neuropathic subjects (CTRL, 2 females and 3 males, 65.2 years old, SD 20) and 5 diabetic neuropathic subjects (DN, 1 females and 4 males, 65.6 years old, SD 10). The protocol is the same as in the first part of the study with the addition of 7 EMG active probes for surface electromyography placed unilaterally (dominant side) on the following muscles: Sternocleidomastoideus (Scm), Rectus Abdominis (RAbd), Erectores Spinae at L4 level (L4), Rectus Femoris (RF), Hamstrings

(Ham), Tibilias Anterior (TA) and Soleus (Sol). All EMG electrodes were positioned over the most prominent part of the respective muscle belly. Muscles activity was recorded using wireless 8-channel surface electromyography (BTS FREE EMG 300, sample rate 1000 Hz). The EMG signals were full-wave rectified and band-pass filtered (35-500 Hz). The analysis was conducted considering the root mean square (RMS) value of SEMG signal. To detect muscles' ON-OFF the double-threshold algorithm described in [4] was implemented. The application of this algorithm requires an estimate of the noise level superimposed at the SEMG signal; consequently it is necessary to record for each channel and for a few seconds a signal with muscle in non-contracted and isometric conditions. For this reason, the data acquisition starts 5 seconds before the voice signal is given to the subject to start the FR task. A simple approach to evaluate the value of the threshold value is to calculate this value at two standard deviations from the mean value. In this study, the threshold has not been computed over the entire noise period (5 seconds) but, within this period, a sliding window of 50 milliseconds has been defined. Within each sliding window, a threshold value has been computed and, between all the threshold values obtained, has been chosen the one with lowest value. The time instants at which the SEMG signal exceeds, or remains below the threshold for at least 50 ms may be considered, respectively, as the ON or the OFF time instants of muscle activity.
The ON–OFF time instants relative to each muscle were averaged over the three trials performed by each subject.

3 Analysis and discussion of main results

Principal component analysis allowed to understand which parameters are more suitable to describe the modalities of the reaching task in the two categories of diabetic subjects. For the CTRL subjects the most important parameters are those related to trunk flexion in the sagittal plane. On the contrary, for DN subjects, the main features are related to upper and lower body rotations. Moreover, the other principal components show that trunk displacement in the medial-lateral direction is also significant in the DN group. So, results reveal that diabetic non-neuropathic and neuropathic subjects use different modalities to perform the FR test. This finding is further confirmed by correlation analysis. These results strengthen the idea of the existence of different execution modalities of the FR test: CTRL subjects perform the task by pushing the trunk forward in the sagittal plane, whereas a higher percentage of DN subjects combine this movement with trunk rotation in association with its displacement in the medial-lateral direction. The above results allow the subdivision of the analysed subjects into two main categories, according to the motor strategies utilised. As shown in Table 1, among the CTRL subjects, 58.8% used "hip" strategy and the remaining 41.2% used "other" strategy. Concerning the latter, 85.7% used "mixed" strategy and only 14.3% the "trunk rotation" strategy. Similarly, in DN patients, 56.7% employ "hip" strategy and 43.3% the "other" strategy but, within in this last group, 62.5% used "mixed" strategy and 37.5% rotated the trunk in order to reach forward. the percentages of subjects which used "hip" or "other" strategies are similar between the CTRL and DN groups. However, within the "other" strategy group, the percentage of DN subjects that use a "trunk rotation" strategy is much higher than for CTRL ones (37.5% DN vs 14.3% CTRL).

Table 1: Motor strategies used during FR test. Number of subjects (N), percentages, mean value (mv), standard deviation (SD) of FR, FR_H (FR normalized w.r.t. subject height) are reported. Mann-Whitney U test results compare FR (and FR_H) values between "hip" and all the other strategies, within CTRL or DN groups, separately ($p \le 0.01$).

* shows statistically significant differences between "hip" and "other" strategies;

† shows statistically significant differences between "hip" and "mixed" strategies;

+ shows statistically significant differences between "hip" and "trunk rotation" strategies.

STRATEGY	CTRL			DN		
	N (%)	FR (mm) mv (SD)	FR_H (mm) mv (SD)	N (%)	FR (mm) mv (SD)	FR_H (mm) mv (SD)
Hip	10(58.8%)	266(38)*†+	0.16(0.02)*†+	21(56.7%)	263(39)	0.15 (0.01)
Other	7(41.2%)	198 (42) *	0.11 (0.01) *	16(43.3%)	227(65)	0.14 (0.04)
Mixed	6(85.7%)	201 (44) †	0.12 (0.01)†	10(62.5%)	223(72)	0.13 (0.04)
Trunk rotation	1(14.3%)	177 +	0.11+	6(37.5%)	233(57)	0.14 (0.03)

This table highlights how similar FR_H (i.e. FR normalized w.r.t. subject height) values can be obtained by different movement strategies. Moreover, the percentages of subjects which used "hip" or "other" strategies are similar between the CTRL and DN groups. However, within the "other" strategy group, the percentage of DN subjects that use a "trunk rotation" strategy is much higher than for CTRL ones (37.5% DN vs 14.3% CTRL). This result highlights how similar FR_H values can be obtained by different movement strategies and this is particularly true for DN subjects. While for diabetic non-neuropathic subjects, FR is mainly performed by trunk flexion in the sagittal plane, for diabetic neuropathic patients, FR is also significantly accomplished by trunk rotation in the horizontal plane.

The EMG activations in neuropathic and non-neuropathic diabetic subjects confirmed that, during the FR task, the prime motor is the TA (Figure 1).

In all subjects, this muscle can be recognized as the first muscle to contract and its action can be attributed to the anticipatory muscular activity necessary to initiate the movement creating useful conditions for forward displacement of the body. Its activation before the movement starts is necessary to move the COP backward and to give rise to the ankle dorsi-flexor moment able to unbalance the body forward.

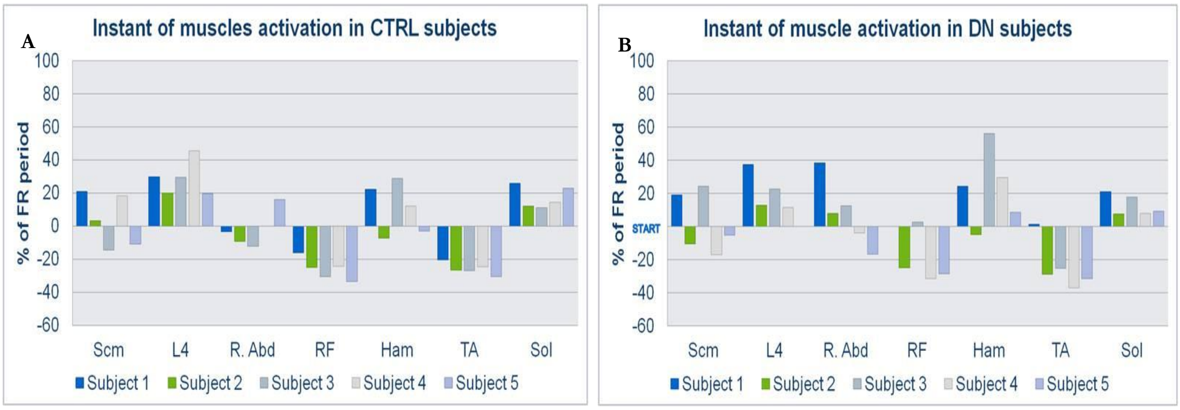

Figure1: Instant of muscle activation in the CTRL (A) and in the DN (B) subjects.

In CTRL subjects, the anterior muscles have a precise activation order from the lower part of the body to the top (TA, RF, RAbd, Scm) following a caudo-cranial order. Therefore, a synergism of the anterior muscle chain exists: this synergism allows the imbalance of the body. In correspondence with 20% of the movement, the posterior muscles begin their activity. There is a synergistic tonic action of Sol and Ham followed by L4 activation. In fact, the back muscles act mainly as tonic muscles that oppose to the movement, preventing falls.

In DN subjects, except for a subject, the TA is activated earlier than its activation in non-neuropathic subjects. The diabetic neuropathic subjects have a problem of proprioception which manifests as a delay in the recruitment of the motor units and as a reduced nervous conduction velocity; consequently it is probable that DN subjects put into action an anticipatory recruitment to compensate for the delay and to adjust the movement timing. This mechanism describes the early muscle predisposition to perform the movement.

In CTRL subjects, two different types of muscle activations have been found: in the first case, the TA is active before the start and turns off immediately after it; in the second case the muscle either has a double activation (before the start and near the end of the movement), or a single prolonged activation for the whole duration of the motor task. On the contrary, in the DN subjects, the TA pattern is unique and has a pattern similar to the CTRL second case. These two muscular patterns identify two different motor strategies used by the subjects. The first modality, characterised by a single activation of the TA, is associated to a mixed strategy (as shown in Table 2 and Table 3) characterized by a reduced flexion of the hip. The second modality, characterised by a double activation of TA (or by a prolonged activation of this muscle), is associated to a hip strategy (Table 2 and Table 3) with a greater hip flexion.

Table 2: Mean value (mv) and standard deviation (SD) of hip flexion, ankle plantarflexion and trunk rotation with the strategy of CTRL groups.

CTRL	**Strategy parameters mv (SD)**				
	Subject A	Subject B	Subject C	Subject D	Subject E
Hip flexion [deg]	18.2 (1.1)	36.9 (1.5)	31.9 (1.8)	18.1 (1.2)	29.5 (2.5)
Ankle plantarflexion [deg]	10.0 (0.3)	26.3 (8.9)	20.0 (2.0)	5.6 (0.3)	10.1 (1.1)
Trunk rotation [deg]	15.1 (3.2)	11.6 (4.1)	12.8 (3.4)	3.7 (2.4)	3.9 (1.6)
Strategy	Mixed	Hip	Hip	Mixed	Hip

Table 3: Mean value (mv) and standard deviation (SD) of hip flexion, ankle plantarflexion and trunk rotation with the strategy of DN groups.

DN	**Strategy parameters mv (SD)**				
	Subject A	Subject B	Subject C	Subject D	Subject E
Hip flexion [deg]	17.5 (3.2)	44.2 (1.9)	26.9 (1.5)	28.7(2.8)	21.1(1.2)
Ankle plantarflexion [deg]	14.2 (0.3)	15.9 (0.5)	15.2 (1.1)	8.6 (2.2)	8.6 (1.3)
Trunk rotation [deg]	11.7 (1.5)	11.8 (2.8)	8.6 (1.8)	6.0 (1.1)	7.4 (1.4)
Strategy	Mixed	Hip	Hip	Hip	Hip

4 Conclusions

In conclusion, as reported in literature [2, 3, 5], the kinematic analysis used to assess the motor strategy adopted during the FR test provides different information on how balance control is performed. When reaching forward with one arm although a great part of movement occurs in the sagittal plane, rotational movements in the transverse and coronal planes also occur and cannot be disregarded.

The results of this study show that diabetic subjects with or without neuropathy adopt different movement strategies during forward reaching. The evaluation of the motor strategy, in addition to the measurement of the forward displacement of the arm, might be useful in the early detection of the subjects at risk of postural instability. Thus the different strategies adopted in the DN group could be due to compensatory mechanisms that allow the maintenance of the dynamic equilibrium while performing a destabilizing task as FR.

From the electromyographic results, it is suggested that the pattern of the anticipatory postural adjustments occurring during the FR (or in similar motor tasks) are nor used exclusively to control the final posture or forthcoming movements perturbation, but create segmental angular acceleration and centre of pressure displacement within the base of support indispensable to move the body forward. Therefore, the muscle activity before the start of the movement could have a primary role in the movement performance and also in the equilibrium control.

So, the evaluation of the motor strategy and the electromyographic analysis of several trunk, thigh and shank muscles, in addition to the measurement of the forward displacement of the arm, might be useful in the early detection of the subjects at risk of postural instability.

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