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DOES THE FUNCTIONAL REACH TEST REFLECT STABILITY LIMITS IN ELDERLY PEOPLE?

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Objective: **To explore how the Functional Reach test correlates with the displacement of the centre of pressure and whether the test is a measure of the stability limits in healthy elderly people. Also to explore the performance parameters during the Functional Reach test.**

Design: **Method comparison study.**

Subjects: **Twenty-seven healthy elderly subjects.**

Methods: **Whole body kinematics (ELITE systems), ground reaction forces (AMTI) and muscle activity (EMG) parallel with clinical yardstick measure while performing the Functional Reach test.**

Results: **This study showed a low correlation ($r = 0.38$) between reach distance and displacement of centre of pressure and a moderate correlation ($r = 0.68$) between forward rotation of the trunk and reach distance. The movement during the Functional Reach test was characterized by a large forward rotation of the trunk and a small extension in the ankle. The latter constraining centre of pressure forward displacement.**

Conclusions: **The results suggest that the Functional Reach test is a weak measure of the stability limits. Movement of the trunk seems to influence the test more than the displacement of the centre of pressure. When using the Functional Reach test for assessing balance, compensatory mechanisms should be taken into account.**

Key words: Functional Reach, balance, centre of pressure, elderly, kinetic, kinematics.

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INTRODUCTION

The Functional Reach test (FRT) is a well-known clinical measure of balance developed by Duncan et al. (1), and tested for both validity and reliability (1–4). FRT measures the distance between the length of the arm and a maximal forward reach in the standing position, while maintaining a fixed base of support. It was developed as a dynamic measure of balance with no attempt to control for the movement strategy (1). FRT is used separately or as an item in Berg's Balance Scale (5) and is used in patients with diagnoses as different as stroke (6), Parkinson (7), vestibular hypofunction (8), multiple sclerosis (9) and hip fractures (10). FRT has also been associated with an increased risk of fall and frailty in elderly people who are unable to reach more than 15 cm (2, 4).

To make sound interpretations, a researcher must be confident that the measurements are reproducible, or reliable. Although reliability is necessary for validity, it does not validate the meaning of the measure. The accuracy or validity of the measurement provided by an instrument can be determined by comparing the reading on the device with a standard measure (11). Laboratory measures of kinematics and kinetics can be regarded as standard measures. Clinical balance tests measure task parameters that reflect what is required from the subject to solve the task but not how the task is performed. Laboratory instruments for balance evaluation, such as analysis of ground reaction forces (kinetics) and of movement (kinematics), measure performance parameters, i.e. how a task or movement is performed and what exactly the subject is doing (12).

The FRT is suggested to be a clinical measure of the stability limits and has been developed from a leaning task (1). Such a task involves displacement of the centre of pressure (CoP) forward by rotating around the ankle joints with maintained hip extension (13). A leaning task also has, like other forward oriented movements, anticipatory muscle activation in the tibialis anterior prior to CoP displacement (14). One way to explore the stability limit is to investigate the location and the path of the CoP during task performance. CoP indicates the location where the resultant ground reaction force has its origin and is directed towards the body (15). Duncan et al. (1) have reported a correlation of 0.71 between CoP displacement and reach distance during FRT. However, the correlation is based on the sum of CoP displacements in anterior/posterior and medial/lateral direction together. FRT, however, assesses only the anterior stability. Duncan et al. (1) have also stated that a reaching task is a more functional task than a leaning task. Yet, we believe that a reaching task may involve other factors than just those of balance.

As a first step towards understanding the relation between task parameters and performance parameters in clinical balance tests, the purpose of this study was: (1) to explore how the interpretation of the FRT correlates with the displacement of CoP and whether FRT is a clinical measure of the stability limits in healthy elderly people; and (2) to investigate performance parameters during FRT with analysis of movement, ground reaction forces and anticipatory muscle activity.

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METHODS

Subjects

Healthy elderly volunteers aged 65–80 years without any history of neurological or musculoskeletal disorders were recruited from pensioners' organizations in the vicinity of Stockholm county, Sweden. Exclusion criteria are listed in Table I. Thirty-three healthy elderly people were enrolled after having given their informed consent. Four were excluded during data analysis due to several missing markers, and 2 subjects were excluded due to the fact that they stood on their toes in all 5 trials. The remaining 27 healthy elderly subjects, 18 women and 9 men, participated in the study. The subjects' mean age was 71.3 (SD 4.0) years and mean height and weight was 167.1 (SD 8.9) cm and 72.0 (SD 12.6) kg, respectively. The subjects did not use any walking aids and were active both indoors and outdoors.

Procedure

The FRT was examined simultaneously clinically by yardstick measure and experimentally by kinetic and kinematic measures. The subject was standing barefoot on 2 force plates and was allowed to make several practice trials before 5 consecutive trials were recorded.

Functional Reach test procedure

The ability of standing subjects to reach with the left hand horizontally forward (90 degrees shoulder flexion and straight arm) while maintaining a fixed base of support was examined. Instructions were similar to those of Duncan et al. (1). A 150-cm yardstick was horizontally mounted on the wall, at the height of the acromion. Reach distance was measured as the displacement of the finger between initial position and end position. In accordance with Duncan et al. (1) the reaching strategy was not otherwise controlled for.

Kinematics

A two-camera optoelectronic system (Elite BTS, Milan, Italy) was used to record the kinematics in a three-dimensional reference system during FRT. The cameras were placed 4 m from the force plates, at 35-degree angles to the sagittal plane. The explored field was 2×2 m, giving an accuracy of 0.78 mm. Spherical reflective markers (diameter 1 cm) were placed on 10 anatomical landmarks on the right side of the body; the mandible joint, the cheek, spinal process C7, L1, L5, the lateral femoral condyle, lateral malleolus, the heel, the fifth metatarsal bone and the acromion. Two markers were placed on landmarks on the left side of the body; the lateral humeral epicondyle and the tip of the third phalanx. In addition, 2 markers were placed as spatial orientation on the wall and on the back corner of the force plate beneath the right foot.

Force plates

The ground reaction forces were recorded on 2 equal force plates (AMTI, Advanced Mechanical Technology Incorporation, model Mc818-6-1000; size 457×203 mm; accuracy 0.25 N). Three orthogonal forces, anterior/posterior, medial/lateral and vertical were measured with strain gauges mounted in the force plates.

Electromyography

Electromyography (EMG) of 4 ankle muscles were recorded with the Bagnoli-8 system, Boston, MA with surface differential electrodes type DE-02 (23×17 mm). The surface electrodes were attached with adhesive tape over the belly of the left and right tibialis anterior and left and right lateral gastrocnemius. EMG data were stored together with the forces on a SC/ZOOM flexible laboratory computer system (Department of Physiology, Umeå University, Sweden) and the kinematics were simultaneously stored together with the forces on the ELITE system computer for further analysis.

Data analysis

FRT was recorded for 5 seconds with a sampling frequency of 100 Hz for kinematic and force plate data and 800 Hz for the EMGs. The data was transformed into ASCII files and analysed by means of Axograph (Axon Instruments), a MacIntosh based software package. Before analysis the force and kinematic signals were digitally filtered for signal smoothing. EMG signals were band-pass filtered between 10 Hz and 1 kHz. Five trials of FRT were analysed for each subject, except for subject 27 who had 4 trials suitable for analysis due to missing markers (a total of 134 trials). The peak amplitude of the finger marker displacement was defined from cursor read-outs and set as the time zero. All other considered peak amplitudes were measured at that instant. Peak amplitudes of trunk and ankle angles were computed as changes relative to the baseline of initial standing. The following angular displacements were measured: trunk segment angle by joining markers on L5 and the right shoulder vs the vertical axis and ankle joint angle by measuring 2 intersecting segments formed by joining markers between the knee and lateral malleolus and the heel and the fifth metatarsal bone. The amplitudes of the force signals were normalized by body mass and expressed as percentage of body weight (%BW). The net CoP displacement was calculated for anterior/posterior and medial/lateral direction. For making comparisons between subjects possible the displacement of CoP was normalized to foot length, i.e. base of support, and presented in the text as a percentage of base of support. The position of marker 14 on the lateral, rear corner of the force plate beneath the right foot was used for transforming the CoP co-ordinates relative to the force plate to the CoP position relative to the foot. The EMG data were analysed in SC/ZOOM and the burst onset latencies were measured relative to the onset of the anterior/posterior force. The onset latency of tibialis anterior and lateral gastrocnemius was defined as EMG activity >2 SD above mean baseline activity and lasting longer than 30 ms. To distinguish anticipatory from feedback activity, anticipatory muscle activity was defined as onset between 40 and 100 ms prior to the onset of the anterior/posterior force.

Statistical methods and analysis

All statistical analyses were performed using STATISTICA for Windows (StatSoft Inc. 2000). Significance level was set at $p < 0.01$ and *t*-test for dependent samples was used to compare the means of dependent variables. Correlation was tested by means of the Pearson product moment correlation. The strength of the correlation coefficient was classified according to Munro (16).

RESULTS

FRT measurement

The mean value of the clinically measured distance (FR_{clin}) was 29.4 (SD 5.4) cm and the experimentally registered displacement of the finger marker (FR_{exp}) was 27.9 (SD 5.6) cm. FR_{exp} was significantly larger ($p < 0.01$) than FR_{clin}.

Displacement of CoP

At initial standing the CoP position in the anterior/posterior direction was mean 36.6 (SD 7.8)% of the base of support starting with 0% at the heel edge and 100% at the toe edge. During FRT performance, CoP initially displaced posteriorly,

Table I. *Exclusion criteria*

Less than 65 years of age
Less than 90 degrees of shoulder flexion
Unable to follow a 3-step command
Unable to stand unassisted for 60 seconds
Diabetes with neuropathy in the lower extremities
Dementia
Hip- or knee-joint replacement
Weight bearing pain in the lower extremities
Decreased hearing or sight
Pathological condition that can influence vestibulary or other sensory systems

mean 8.1 (SD 3.7)% or 2.0 (SD 0.9) cm, and thereafter moved anteriorly, mean 37.4 (SD 10.6)% or 9.2 (SD 2.6 cm), as shown in Fig. 1.

Thereby CoP displaced anteriorly 29 (SD 8.3%) or 7.2 (SD 2) cm from the initial position, which was used in the correlation analysis. The end location of CoP was at 65.8 (SD 5.6)%. The pattern of the CoP displacement was similar for all subjects but differed between starting position and amplitude of the posterior and anterior displacement. FR_{clin} distance had a low correlation to the anterior displacement of CoP ($r = 0.40$) and the correlation was still low ($r = 0.38$) when normalized to base of support (Fig. 2). There was also a low correlation between FR_{clin} and the posterior displacement of CoP ($r = 0.26$).

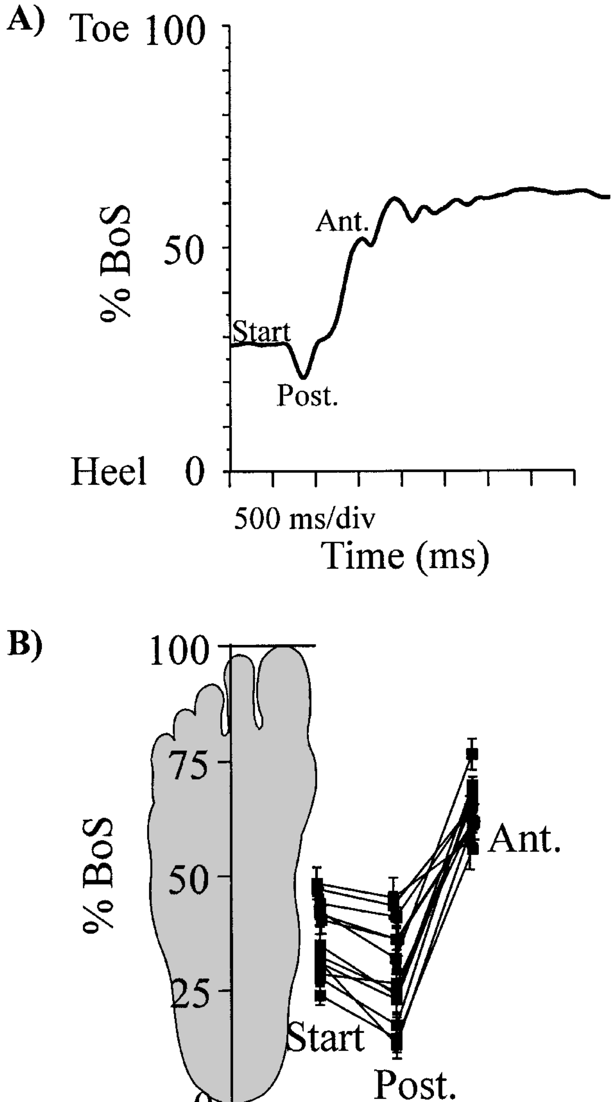

Fig. 1. (*A*) Displacement of centre of pressure (CoP) expressed as percentage of base of support (%BoS) in 1 trial in 1 subject. (*B*) Subject mean and SD of CoP initial position (Start), peak posterior displacement (Post) and peak anterior displacement (Ant) are expressed as percentage of base of support during forward reaching. The mean and SD is shown for 13 subjects, representing the range of all subjects. For clarity, the posterior and anterior measures are plotted with a lateral offset.

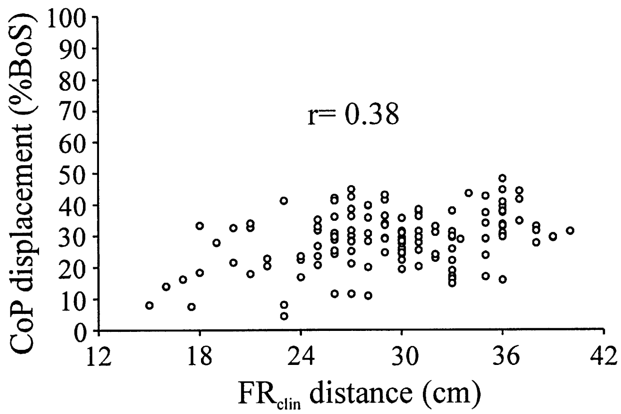

Fig. 2. Relation of centre of pressure (CoP) anterior displacement expressed as percentage of base of support (%BoS) and FR_{clin} distance for all trials.

Angular displacement during FRT

The mean forward rotation of the trunk during FRT was 32 (SD 9.6) degrees. From initial standing, the ankle angle increased towards extension in 90% of the trials, mean 6.7 (SD 3.4) degrees, and for the remaining 10% it either remained similar or decreased towards flexion, mean 2.0 (SD 1.3). Trunk forward rotation and ankle joint angle both increased as FR_{clin} increased. FR_{clin} and trunk forward rotation showed a moderate correlation, $r = 0.67$ (Fig. 3) and FR_{clin} and ankle joint angle showed a low correlation, $r = 0.39$.

Age and height

The results showed no significant ($p > 0.05$) correlation between FR_{clin} and age and height ($r = -0.27$ and $r = 0.22$, respectively).

Weight distribution and muscle activity

Analysis of the weight distribution normalized to body mass during FRT showed a larger ($p < 0.001$) weight beneath the left

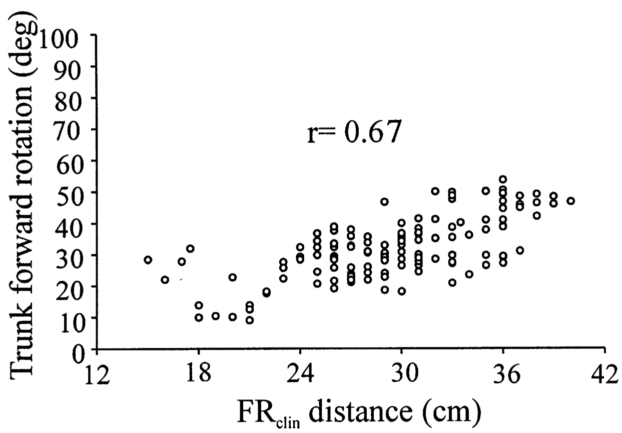

Fig. 3. Relation of forward rotation of the trunk and FR_{clin} distance for all trials.

leg than beneath the right, 59 (SD 7.0)%BW and 42 (SD 7.3)%BW respectively, at initial standing. When reaching forward the subjects increased loading on the left leg with 5.8 (SD 8.1)%BW ($p < 0.001$). Onset of activation in the tibialis anterior was found in the right tibialis anterior 57 (SD 15) ms and the left tibialis anterior 56 (SD 15) ms prior to the onset of anterior/posterior forces in 16 and 13% of the trials distributed on 13 and 12 subjects, respectively (Fig. 4). In these trials onset of activation of the lateral gastrocnemius occurred 367 (SD 107) ms in the right lateral gastrocnemius and 327 (SD 141) ms in the left lateral gastrocnemius significantly later than the right tibialis anterior and the left tibialis anterior onset ($p < 0.001$).

DISCUSSION

In this study the correlation between reach distance and displacement of CoP suggests that FRT does not reflect the stability limits in healthy elderly people. Only 15% ($r^2 = 0.15$) of the variation in CoP displacement could be explained by how far a subject could reach during FRT, leaving 85% of the variation to other factors. Our results showed that the reaching task is more influenced by other factors, such as the movement of the trunk. We found that the movement during FRT consisted of a large forward rotation of the trunk and a small extension in the ankle. EMG activity in tibialis anterior and lateral gastrocnemius showed no clear muscle activation pattern prior to the reaching movement. However, anticipatory postural adjustments could be seen in CoP as a posterior displacement of CoP prior to the onset of forward reach in all subjects.

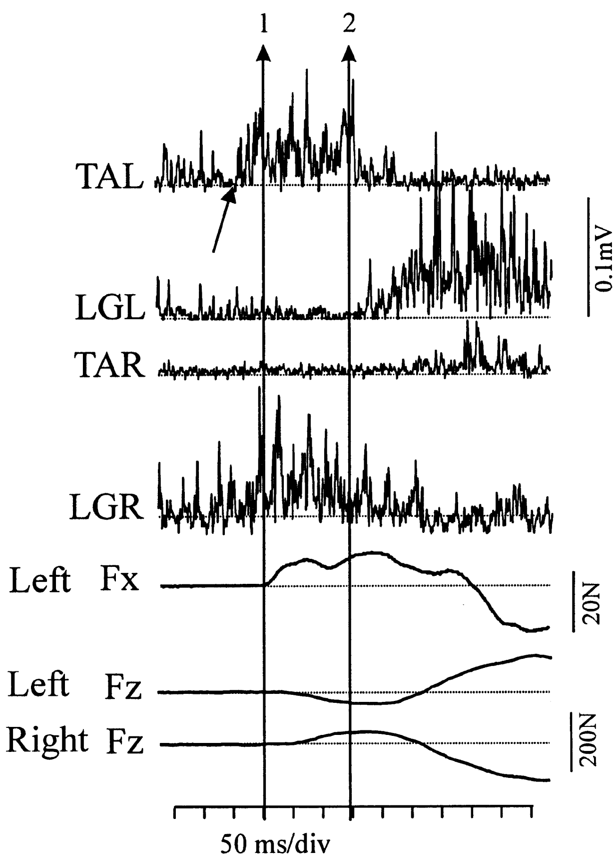

Fig. 4. Single time traces of ankle muscle EMG, vertical force (Fz) and anterior/posterior force (Fx) for the initiation of the Functional Reach test in one of the 12 trials that had an anticipation activity in left tibialis anterior (TAL). Scale bars are to the right. Number 1 indicates the onset on Fx and 2 indicates the onset of the finger marker. Note, the arrow indicating an anticipatory activity prior to Fx in TAL. Abbreviations: LGL, left lateral gastrocnemius; TAR, right tibialis anterior; LGR, right lateral gastrocnemius.

The mean FR_{clin} distance of the healthy elderly subjects in this study were similar to that of Duncan et al. (1) and Wernick-Robinsson et al. (8). We found that the significant difference between FR_{clin} and FR_{exp} can be related to the experimental setting in which FR_{exp} was recorded for 5 seconds. Despite that the subjects reached the onset of the plateau of forward displacement within the 5-second time frame, some subjects, however, extended the reach distance with 1–2 cm during the time interval (about 2–5) seconds between end of recording and yardstick measure. Measuring with the yardstick (FR_{clin}) resulted in larger amplitudes compared with FR_{exp} due to some subjects inability to maintain the end position.

The moderate correlation found by Duncan et al. (1) may be explained by the associated medial/lateral displacement of CoP since they correlated the sum of CoP displacements in both anterior/posterior and medial/lateral direction with the reach distance. FRT is an asymmetric task and therefore a lateral CoP displacement towards the reaching arm will occur together with the weight shift during FRT. Another explanation may be that Duncan et al. (1) studied the correlation in a group with a much larger age span (aged 21–87 years). Our results showed no significant correlation between age, height and FR_{clin} similar to the results of Wernick-Robinsson et al. (8) even though their results showed that height and age are significant factors influencing reach distance.

Limits of stability are not the same as balance, but are one aspect of balance (15). Since balance control is a complex entity, it is difficult for a single test to measure all its aspects. However, it is important to specify what aspect of balance a test measures and to validate that the test does in fact reflect this aspect. The definition of stability limits changes with the task, the subjects' biomechanics and the environment. The discrepancy between one subject's "perceived" and "actual" stability limits is a potential source of uncertainty and should be explored further. Exactly how we can best measure stability limits in different directions is, however, somewhat unclear (13, 17, 18) and further research is needed. Theoretically, it should be determined by the extent of ankle extension. In this study 90% of the trials resulted in a tendency toward an ankle extension associated with the task. It seems that the trunk forward rotation was associated with a backward shift of pelvis and ankle extension. This movement pattern has been seen as a compensatory postural adjustment during trunk bending movements, where the hip and knee moves in the opposite direction to that of the upper trunk (19).

CoP anterior displacement in this study is consistent with the results of Wernick-Robinson et al. (8). Notably, similar anterior displacement of CoP was seen during a leaning task in elderly people (13) indicating that the CoP displacement during reaching is not larger than during leaning. We found a starting position that ranged from 23 to 49% of base of support, similar to the results of Crenna & Frigo (14) who found the starting position to be slightly anterior of the lateral malleolus during upright stance. Another study (18) has reported a mean position of CoP in double limb standing as 11.5 (SD 2) cm forward from the heel edge, which should be approximately 40–50% of base of support in our subjects.

Anticipatory postural changes are associated with voluntary movements. The posterior displacement of CoP seen prior to the reaching movement is an anticipatory adjustment to create a distance between CoP and centre of mass location (moment arm) (14). Prior to the beginning of a voluntary movement and CoP posterior displacement, muscle activation can be recorded in muscles other than the primary movers. Crenna & Frigo (14) reported anticipatory postural adjustments in the tibialis anterior and soleus before the initiation of a forward oriented arm movement. Surprisingly, we only found anticipatory tibialis anterior activity in 13% (right leg) and 16% (left leg) of the trials. The lack of an anticipatory postural adjustment pattern in the tibialis anterior as well as the initial weight distribution towards the left leg may be due to the fact that the initial position places the subject in a already prepared position or that it is speed-related and due to the slow movement during FRT (20). This may question whether this reaching task does in fact represent a functional volitional movement. Further research is needed to investigate if other muscles have anticipatory activity during FRT.

Although, FRT has proven to be reliable and valid (1–4) there are major factors influencing the evaluation. Wernick-Robinson et al. (8) found that the movement strategy influenced FRT and recommend to assess movement strategy during FRT. Other researchers (21, 22) implicate that a reduced spinal flexibility results in reduced reach distance, while still others question FRTs ability to differentiate elderly non-fallers from fallers (17). Our results suggest that FRT is a weak measure of the anterior stability limits in standing. Yet this study was limited to dealing with correlation. However, the quality of the displacement of CoP needs further investigation.

If FRT is to be used as a balance test one has to consider compensatory mechanisms for decreased flexibility and strength interfering with the evaluation. We believe that a leaning task may be more valuable for measuring the limits of stability and recommend further research to develop a clinical measure that reflects the stability limits in both anterior/posterior and medial/lateral direction.

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