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# Associations between measures of gait stability, leg strength and fear of falling

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ABSTRACT

Fear of falling (FoF) in elderly frequently leads to decreased quality of life. FoF is suggested to be associated with changes in gait quality and muscle strength with aging. The aim of this study was to determine whether gait quality and maximal voluntary torque (MVT) of knee extensor muscles are associated with FoF. We hypothesized that high between-stride variability and local divergence exponent (LDE) of trunk kinematics in gait are associated with higher FoF in non-fallers, but not in fallers. Moreover, we hypothesized that knee extensor muscle strength is associated with a high variability and LDE of trunk kinematics during gait.

134 four adults, aged 62.4 (SD 6.2) years agreed to participate. FoF was assessed on a 10-point numerical rating scale. Subjects with at least one fall in the past 12 months were considered as fallers. LDE and variability were calculated from data of a trunk-mounted inertial-sensor collected during several minutes of treadmill walking. Maximal voluntary knee extension torque (MVT) was assessed isometrically.

Fall history was an effect modifier in the association between LDE and FoF only, i.e. only subjects without fall history and a high LDE had a five times higher chance of reporting FoF. Gait variability was not associated with FoF. Low MVT was associated with FoF. Multivariate analysis demonstrated that LDE was more strongly associated with FoF than MVT.

Decreased stability of gait as reflected in a high LDE and low muscle strength are associated with and a potential cause of FoF in subjects without fall history.



## 1. Introduction

Fear of falling (FoF) frequently leads to activity restriction resulting in decreased quality of life [1]. FoF is also associated with fall risk [2]. However, the causal relationship between FoF and falling itself is not clear and can be bi-directional. FoF may be the result of a fall, but it may also increase falls risk. As people age, the quality of gait becomes less because of negative changes in the neuromusculoskeletal system. The perceived loss of balance in static as well as dynamic situations in daily life, including possible near falls, may induce FoF. To develop interventions against FoF, knowledge about the associations between falling, FoF and the age-related changes in quality of gait is necessary.

Age-related deterioration of gait quality is apparent in measures such as variability and local dynamic stability of trunk kinematics [3,4]. Variability in trunk kinematics during gait can be quantified by the standard deviation of trunk kinematics between strides. Local dynamic stability can be assessed by the local divergence exponents (LDE), which is quantified as the rate of divergence of the kinematics after very small, naturally occurring, variations [5]. A high LDE indicates fast divergence and hence low local dynamic stability. Generally, a high LDE and large variability of trunk kinematics in gait are indicators of a decreased gait quality [6–10]. Although gait variability is associated with falls risk [8,9],

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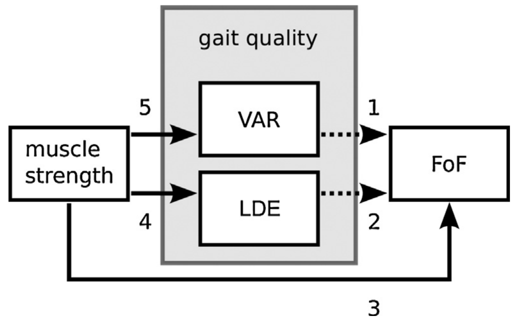


**Fig. 1.** Conceptual model of the associations (numbered 1–5) proposed in the introduction. VAR is variability; LDE is local divergence exponent; FoF is fear of falling. Solid lines indicate confirmed associations, dotted lines indicate unconfirmed associations.

an association with FoF could not be confirmed (Fig. 1, association 1) [8,9,11]. Also LDE is associated with fall risk [10,12], but, to the best of our knowledge, the association between LDE and FoF has not yet been investigated (Fig. 1, association 2). It is conceivable that the association of gait variability and LDE with FoF differs between subjects with and without fall history, as in fallers FoF is probably strongly determined by (the consequences of) recent falls.

Aging is associated with decreased muscle strength, and decreased muscle strength has been associated with FoF in adults over 70 years [2] (Fig. 1, association 3). In addition, decreased leg strength has been associated with gait variability in adults over 70 years [8,13,14] and with LDE in a study with young and elderly subjects [15]. However, associations of muscle strength with variability and LDE of trunk kinematics in gait (Fig. 1, associations 4–5) in older adults have not been reported.

The first aim of this study was to determine whether the variability and the LDE of trunk kinematics in gait and leg muscle strength are associated with FoF (Fig. 1, associations 1–3) in healthy older adults. The second aim was to assess whether leg muscle strength is associated with the variability and LDE of trunk kinematics during gait (Fig. 1, associations 4–5).

An association between gait characteristics and FoF may indicate that changes in gait quality induce FoF. If so, FoF could in part be caused by gait changes and in part be remedied by interventions that target the underlying physical causes rather than FoF itself. We targeted healthy adults from 50 years and older, to obtain a sample with a wide range in gait characteristics and muscle strength, including individuals with FoF but no history of falls. We hypothesized that high variability and LDE of trunk kinematics during gait are associated with FoF in non-fallers, but not in fallers. Moreover, we hypothesized that leg muscle strength is associated with a high variability and LDE of trunk kinematics during gait.

## 2. Methods

### 2.1. Participants

Subjects were recruited and tested at a national fair aimed at people of 50 years and older. Subjects were included if they were aged between 50 and 75 years and able to walk on a treadmill without walking aids. All subjects signed informed consent. The ethics committee of the Faculty of Human Movement Sciences, VU University Amsterdam, approved the experimental protocol, which was in accordance with the declaration of Helsinki.

### 2.2. Experimental protocol

Subjects walked for 12–17 min on a treadmill at 1.1 m/s. The first 5–10 min were used to become familiar with treadmill walking. During the final 7 min, trunk accelerations and angular velocities were recorded at 100 Hz using an inertial sensor (Dynaport Hybrid, McRoberts B.V., The Hague, The Netherlands). The sensor was strapped to the back, just below the shoulder blades, as trunk control is critical for gait stability [16]. Sensor axes were aligned with the anatomical axes of the trunk in upright stance.

Maximal isometric voluntary knee extension torque (MVT) of the right leg was measured, while the subjects were seated on a custom made dynamometer with hip and knee joints fixed at an angle of 90°. The lower leg was strapped to a force sensor 0.245 m below the knee joint. Subjects were asked to provide as much force as possible for approximately 3 s. The subjects performed three MVT trials with verbal encouragement, separated by 1 min rest. If the final MVT exceeded the previous values by more than 10%, an additional trial was performed. The subjects received online visual feedback, on whether their attempt was higher or lower than the previous MVT. If a subject was unable to perform the MVT assessment with the right leg, the measurement was performed on the left leg (8 out of 130 subjects).

FoF was assessed by asking the subjects to rate their FoF when they performed activities of daily living on a 10-point numerical rating scale (1 = no fear at all, 10 = extremely fearful). A systematic review on psychological outcomes of falling showed that single-item questions are regularly used and, though only limited data are available, clinimetric properties are good [17]. For the question used in the present study, the validity and reliability are reported to be moderate to fair [18]. Fall history was obtained by self-report of number of falls in the last year. A subject was classified as a faller if at least one fall had occurred in the past 12 months. Subjects were classified as experienced treadmill walkers if they had walked on a treadmill at least twice before the measurements.

### 2.3. Data analysis

Before calculating MVT, the force data of the time series of all MVT trials were filtered using a 4th order Butterworth 150 Hz low-pass filter. The MVT was defined as the maximum of the filtered force signal multiplied by the moment arm (0.245 m) and divided by body mass [19].

3D trunk accelerations and angular velocities were analyzed in the sensor coordinate system, which was approximately aligned with the global coordinate system [20]. The final 150 strides were used to calculate gait parameters. Foot contacts were estimated based on the anterior-posterior acceleration signal for all gait parameters [21]. In short, after low-pass filtering of the AP acceleration signal (20 Hz, 4th order Butterworth), zero-crossings were determined and subsequently the peak forward acceleration preceding the zero-crossing was taken as the instant of foot contact. This method has been shown to yield a systematic offset, which does not affect the present analysis, and a small random error in comparison to foot contact detection using ground reaction forces [21].

To quantify variability and local dynamic stability of trunk kinematics during gait we used the variability of medio-lateral (ML) trunk acceleration and the LDE of the 3D trunk angular movement, respectively. In a factor analysis on a range of gait measures, these measures showed the highest factor scores within the clusters of gait parameters reflecting variability and stability respectively [10]. Gait variability was assessed by the standard deviation of ML trunk accelerations between strides ($VAR_{ML}$). The ML acceleration data were low-pass filtered (20 Hz, 4th order Butterworth). Based on foot contact data, each of 150 strides was time normalized (0–100%). At each of the 100 normalized time points the standard deviation of the ML trunk acceleration over the 150 strides was calculated. Subsequently, the mean standard