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Relation between knee extensors' strength, postural stability and variability of centre of pressure displacement during gait in adult women

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Background: It has been shown that variability of walking is related to fall risk similarly as postural control and muscle strength. Joint potential of this group of variables for fall risk assessment is promising, however research interested in relations between them is lacking. **Objective:** The aim of this study was to investigate the relation between knee extensors' strength, centre of pressure (COP) velocity during one-leg stance and variability of COP displacement during various phases of gait cycle in middle-age women. **Methods:** A single group of 40 healthy women (age 56 ± 4.2 years) took part in the study. For assessment of knee extensors' strength (peak torque and average work during concentric and eccentric contractions) an isokinetic dynamometer was used. Mean velocity of COP during one-leg stance in anterior-posterior (AP) and medial-lateral (ML) directions was assessed on a force plate on a rigid surface with eyes open (two 30 s trials). Variability of COP displacement was assessed for loading response, midstance, terminal stance and preswing gait cycle phases (determined by vertical ground reaction force) in AP and ML directions. It was measured by two force plates positioned in the middle of an 8 m walkway (5 trials at a self-selected speed). For statistical analysis of relationships between variables Pearson correlation was applied. **Results:** Our results showed significant correlations between eccentric peak torque and COP velocity in AP direction during one-leg stance, eccentric and concentric peak torque and COP variability during loading response in both ML and AP directions and during terminal stance in AP direction. **Conclusion:** Loading response and terminal stance seems to be more related to knee extensors' strength. Variables derived from postural stability assessment during one-leg stance are independent from variables derived from assessment of COP displacement variability during walking.

Keywords: centre of pressure (COP), force, postural instability, gait cycle, walking

Introduction

Falls and unstable balance situations are a cause of substantial rates of mortality and morbidity as well as major contributors to immobility and premature nursing home placement (Rubenstein, 2006). It is desirable to identify fall risk also in the middle-aged population, because these subjects could be recommended to exercise programs earlier to reduce the number of falls.

There are many factors, which can influence fall risk. With the aging process there is a reduction of lower limbs strength (Borges, 1989; Horak & Macpherson, 1996; Keller & Engelhardt, 2013; Lindle et al., 1997) which is considered as a predictor of worsening mobility (Lauretani et al., 2003). Other factor which could be associated with fall risk is strength difference between limbs (Perry, Carville, Smith, Rutherford, & Newham, 2007; Skelton, Kennedy, & Rutheford, 2002) and intensity of physical activity (Lehnert, Svoboda, & Cuberek, 2013).

Assessment of fall risk is also often associated with the level of balance. It could be investigated by measurement of postural stability, however some tests are less demanding and thus insufficiently sensitive for prediction of fall risk (Melzer, Benjuya, & Kaplanski, 2004). In this case it could be made more difficult e.g. by reducing proprioceptive feedback of the feet (Fujimoto et al., 2012). For example we can use a one-leg stance instead of bilateral stance.

Another approach presented Bizovska et al. (2014). As potential indicator of fall risk they considered variability of centre of pressure (COP) displacement

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during gait. It was shown that dynamic compared to static conditions, correlates more with measurements of strength, flexibility, physical activity, body composition and bone health, which are also considered as balance predictors (Weirich, Bemben, & Bemben, 2010).

Assessment of COP displacement variability is a relatively new tool and we did not find any research which focused on the relationship between variability of COP during gait, postural stability measures and lower limb muscle strength.

The aim of the study is to investigate the relationships between knee extensors' strength, COP velocity during one-leg stance and variability of COP displacement during various phases of gait cycle.

Methods

Participants

The population was recruited from regional institutions in Olomouc, Czech Republic. Inclusion criteria for participation in the study were age between 50 and 65 years, the ability to walk without an assistive device, the ability to stand unassisted without any support during common everyday activities. The criterion for exclusion consisted of current or previously known neurological, cognitive or other diagnoses or medications affecting balance or walking.

In total, 40 women participated in the study and were all addressed to a single group. The basic characteristics of the observed group was age 56.0 ± 4.2 years, body height 164.4 ± 5.8 cm, weight 77.8 ± 18.7 kg, BMI 28.7 ± 6.3 $kg \cdot cm^{-2}$.

This study was approved by the institutional research Ethics Committee and all subjects signed the written informed consent before measurement.

Procedures and data analysis

To assess the level of postural stability, the displacement of COP during one-leg stance was recorded. Tests were performed with eyes open focused on a small mark (1.5 cm in diameter) placed 1 meter ahead of the participant in the eye level. Participants were firstly asked to maintain a stable bipedal posture focusing their eyes on the mark and after reaching stability, lift one of the lower limbs. Secondly, participants were asked to maintain this unipedal posture "as stably as possible" for 30 seconds without trying to maintain their balance by waving their upper limbs. A trial was considered as a successful trial during which not once bipedal contact was attained and lower limbs were not in contact with each other making the task easier. In each case, two tests for each limb were performed and then averaged. The measurement started 3–5 seconds after attaining unipedal stance. The selected indicators of postural deviations were: average velocity of COP displacement in the medial-lateral (ML) direction (Vx) and anterior-posterior (AP) direction (Vy). A higher velocity indicates a worse level of postural stability. COP displacement was recorded using a Kistler force plate (type 9286 AA, Kistler Instrumente, Wintherthur, Switzerland) with a sampling rate 200 Hz. The data was exported and processed offline in the Matlab software (Version R2010b; Mathworks, Natick, MA, USA). The filtration was performed using a 4^{th} order low-pass Butterworth filter with a cut off frequency of 7 Hz.

To asses COP displacement variability during gait we followed the procedures used by Bizovska et al. (2014). Subjects walked barefoot along an 8 m walkway at a self-selected speed. The COP displacement was recorded using two force plates Kistler 9286 AA (Kistler Instrumente, Winterthur, Switzerland) placed in series in the middle of the walkway with a sampling rate of 200 Hz. The subjects performed 3 to 5 trials for familiarization a 5 trials for analysis.

To identify the stance phases, lower limit of the vertical component of the ground reaction force was set to 5% of the subject's body weight. The data were filtered in Matlab software (Version R2010b; Mathworks, Natick, MA, USA) using the 3^{rd} order low-pass Butterworth filter with a cut-off frequency of 30 Hz.

According to the behaviour of the ground reaction force, each stance phase was divided into four subphases: loading response (period between initial contact and first vertical peak), midstance (period between first vertical peak and minimal value of vertical force between peaks), terminal stance (period between minimal value of vertical force and second vertical peak) and preswing (period between second vertical peak and toe off) (Ayyappa, 1997). Standard deviation of COP displacement in the ML (Dx) and AP (Dy) directions were computed for each subphase. All of the calculations were performed using custom-written Matlab algorithms (MATLAB R2010b; Mathworks, Natick, MA, USA).

The knee extensors' bilateral isokinetic strength of the lower limbs during concentric and eccentric contractions was measured using an isokinetic dynamometer IsoMed 2000 (D. & R. Ferstl, Hemau, Germany). For the assessment of isokinetic strength, the absolute peak torque ($N \cdot m$) and average work (J) were used. The test followed the procedures used by Cuberek et al. (2014) and was preceded by a non-specific warm-up which consisted of cycling on a stationary bicycle ergometer for 6 minutes of low to moderate intensity, stretching of the main muscle groups involved during testing and ten semi-squats with increasing movement range. The warm-up routine was performed under the supervision of a researcher. The women were tested in a sitting position with their arms along the body and holding the chair handles. The angle of the backrest of the chair was 15°, the angle of the hip was approximately 100°. The tested individual was fixed in the area of the shoulders, pelvis and thigh of the working leg. The axis of rotation of the dynamometer was identical with the axis of rotation of the knee joint (lateral femoral condyle). The arm of the dynamometer lever was fixed in the distal area of the lower leg, located 2.5 cm above the medial malleolus. The range of movement was 80°, the initial position was 10° of flexion, and the final position was 90° of flexion in the knee joint. An angular velocity of $180° \cdot s^{-1}$ was used during the measurement. Gravitational correction was activated during the measurement. The testing protocol consisted of two sets (training and testing). The training set consisted of five eccentric and concentric reciprocal actions (flexion to be first) with a gradual increase in the intensity of muscle action until maximum. The subsequent testing set was performed after a two-minute recovery interval and included a set of three eccentric and concentric reciprocal actions with a maximum effort.

Statistical analysis

Statistical analysis was performed using Statistica software (Version 12.0; StatSoft, Tulsa, OK, USA). Data from right and left limbs were averaged. Normal data distribution was verified by Kolmogorov-Smirnov test. For statistical analysis of relationships between variables Pearson correlation was applied. Significance level was set at $\alpha = .05$.

Results

A significant correlation between postural stability and knee extensors' strength was found between peak torque during eccentric contraction and COP velocity in AP direction (Table 1).

Table 1

Correlation between knee extensors' muscle strength and postural stability

Parameter	Vx	Vy
Peak torque eccentric	−.29	−.38*
Average work eccentric	−.21	−.31
Peak torque concentric	−.10	−.20
Average work concentric	−.07	−.10

Note. Vx = average velocity of the COP in the medial-lateral direction; Vy = average velocity of the COP in the anterior-posterior direction. $^*p < .05$.

Significant correlation between knee extensors' muscle strength and variability of COP displacement (standard deviations) during walking were found during loading response in both ML and AP directions and during terminal stance only in AP direction (Table 2).

No significant correlation was found between postural stability during one-leg stance and variability of COP displacement during walking.

Discussion

Postural stability is traditionally considered as fall risk indicator similarly as muscle strength. In our study we found significant correlation between peak torque during eccentric contraction and one-leg stance in AP direction, however correlation coefficient is relatively low (.38). Similar findings presented Wu, Zhao, Zhou, and Wei (2002). They found that the COP excursions correlated significantly with the eccentric strength of knee extensors but not with the concentric strength of knee extensors.

Regarding variability of COP displacement during walking, our study showed significant correlations between eccentric and concentric peak torque and COP variability during loading response in both ML and AP

Table 2

Correlation between knee extensors' muscle strength and standard deviations of COP displacement during various subphases of walking

	Loading response		Midstance		Terminal stance		Preswing	
Parameter	Dx	Dy	Dx	Dy	Dx	Dy	Dx	Dy
Peak torque eccentric	−.36*	−.54*	−.02	−.08	−.02	−.38*	.03	.28
Average work eccentric	−.33	−.49*	.08	−.06	.06	−.38*	−.05	.13
Peak torque concentric	−.49*	−.41*	−.16	−.18	−.18	−.56*	.05	.30
Average work concentric	−.47*	−.33	−.20	−.27	−.20	−.56*	−.11	.14

Note. Dx = standard deviation of the COP displacement during walking in the medial-lateral direction; Dy = standard deviation of the COP displacement during walking in the anterior-posterior direction. $^*p < .05$.

directions and during terminal stance in AP direction. All significant correlations were negative. Meaning that higher muscle strength is associated with lower variability of COP displacement. Similar findings were confirmed by other studies, which presented that stronger subjects have better stability during gait (Persch, Ugrinowitsch, Pereira, & Rodacki, 2009; Weirich et al., 2010).

We did not find any significant correlation between one-leg stance and variability of COP displacement during walking. Thus our results suggest that postural sway during standing and during walking are almost independent. This finding support other which showed that performance in the static balance test was not reflective of performance in the dynamic balance test (Hrysomallis, McLaughlin, & Goodman, 2006; Karimi & Solomonidis, 2011).

One leg stance was chosen due to higher demands. These conditions are closer to dynamic conditions in comparison with bipedal stance so we expected that this test would better correlate with postural sway during walking (variability of COP displacement). This expectation was not confirmed even for single limb support phases when position of body is similar as during one-leg stance. It is questionable what approach (static measurement, dynamic measurement during walking) is better for fall risk prediction. Some authors presented that usability of most of the traditional COP variables derived from postural stability assessment is limited (Muir, Kiel, Hannan, Magaziner, & Rubin, 2013). The potential of variability of COP displacement during walking for fall risk prediction has not been sufficiently observed yet. It was shown that older subjects have higher variability of COP displacement during loading response and pre-swing phases (Bizovska et al., 2014). The difference in COP variability was showed also between preferred and non-preferred limbs (Svoboda et al., 2015).

Our study also has some limitations, especially the number of repetitions mainly for one-leg stance should be higher. However we consider possible fatigue of participants due to several evaluated tasks.

Conclusion

The findings of our study have shown that displacement of the centre of pressure correlates with knee extensors' muscle strength in both static and dynamic conditions. Most suitable phases for dynamic balance assessment during gait seem to be loading response and terminal stance. An important finding of our study is also the fact that variables derived from postural stability assessment during one-leg stance are independent from variables derived from assessment of COP displacement variability during walking.

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Conflict of interest

There were no conflicts of interest.

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