

Balance control contributors – the relationships between leg strength and balance control ability in seniors

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The paper presents a study on leg strength as a balance control ability contributor. 9 seniors with the average age of 69.8 years participated in the experimental study. A psychomotor efficiency timer and a standard stabilograph were used in the study. The timer consisted of a computer, a controller and an arm and leg strength measurement station. The subjects performed stepping up movements with the left and right leg in response to two audio-visual signals. The strength of legs was measured indirectly by the time of straightening the first leg put on the step-box. The balance control ability was tested on the basis of the length of the line of center pressure oscillations in the standing position on a force platform. The relationships between the tested factors were examined on the basis of Pearson's correlation. We have found a strong correlation between the balance control ability and the left (0.77) and the right (0.83) leg relative strength and correlation between the strength of the left and the right leg (0.95). Our study has shown that relative leg strength may be treated as a contributor to postural balance control ability.

Key words: stepping up, leg strength, balance contributor, seniors

1. Introduction

An increase in the economic level of many countries results in an improvement of the citizens' health and life expectancy. Older people, who live longer and independently, also have higher social expectations. These factors, i.e., better health, longer life and higher social expectations, result in a need to develop wide scientific studies on the contributors to health and efficiency of older people to prevent and slow down the aging process [2], [3], [16], [26], [27], [31]. The study of the factors related to the efficiency of older people, that have influence on safety of their motor behavior, seem to be specially important. To these factors we have included balance control ability.

The ability is a very important element of psychomotor efficiency in everyday life. The efficiency is understood as the effectiveness of the brain and body cooperation in every day motor behavior. We treat all mental, motor and psychomotor factors the improvement of which causes an increase in balance keeping ability as contributors to the ability.

The research on postural balance control ability contributors was mainly conducted with respect to attention, reaction time, speed of stepping, muscle strength and power, recovering from falls and predicting the risk of falls. SHUMWAY-COOK and WOOLLACOTT [23] have found that a low ability to locate (direct) attention to postural control under multitask conditions may be a contributing factor to imbalance and falls in older adults. Similar results were obtained by SIU and colleagues [24], who have

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shown that an ability to switch attention flexibly when simultaneously performing a postural and secondary cognitive task can be predictive of the ability of postural control. ZETTEL and co-workers [32] suggest that impairment in attention switching in the ability of lateral stability control during stepping reactions in older adults may be an important contributor to an increased risk of falling. In seniors also the impaired ability to initiate and execute quick, accurate voluntary steps was found, particularly in situations where attention is divided [19]. In this study it was also found that the time of stepping reaction discriminates between older people who had and had not falls. In the test applied in the study subjects stepped with the left or the right leg onto targets randomly illuminated. This experiment simulated unanticipated changes in the gait path. Age differences were also found in factors related to the stepping reacting speed that could be contributors to the postural balance control ability. Compared with the young, older people initiate and execute voluntary steps more slowly [14], and the differences are larger in situations where attention is divided [6], [7]. A study on the ability to recover from a fall has shown that the ability depends largely on the maximum stepping speed. WOJCIK and colleagues [30] have found a strong correlation between stepping speed and the ability to recover from a forward fall in seniors. In turn, THELEN and co-workers [28] suggested that the maximum stepping speed lower in older adults than in young adults constitutes the limits in the ability of older adults to recover from falls. These researchers suggested that the reduction in the maximum stepping speed can be caused by an individual reduction in peak joint velocity of a particular joint (i.e., hip, knee, or ankle) for both occurring in steps directions (i.e., flexion and extension) of leg segments movements.

In the aspect of age changes in the postural balance control ability the age differences between young motor active women and older women were also tested [13]. Contrary to expectations, motor active young women demonstrated larger movements of the center of pressure (COP), lesser stability to maintain the standing position indicated by a larger sway area of deflections of COP and the scope of vertical movement of center of gravity than older women. The study suggested that the standard posturography method may not discriminate between the balance control ability of young, highly efficient and older subjects, probably because young people perform postural correction movements faster than older people, and the inertia of the body causes larger sways of COP in the young. To examine the limits in a stability

test conducted on a force platform, JURAS and co-workers [8] presented different ways of estimating the maximal center of pressure excursion. The study has shown a reliability of chosen parameters of limits in the stability and no significant differences between them. The research of SKELTON and colleagues [24], [25] indicated that muscle strength and power may play an important role in stepping movements to recover from a fall in seniors. The study has also shown asymmetries in strength and power between the left and the right leg.

The muscles activation as anticipatory postural adjustments in tasks involving two sequential perturbations was also tested [22]. The obtained results suggest that the investigation of sequential actions initiated in the standing position should take into consideration postural adjustments which may have influence on the shape of movements performed. ASAKA and WANG [1] tested age differences between postural muscles covariate patterns prior to voluntary perturbations. The results obtained in this study indicate that the older group demonstrated changes in the anticipatory postural muscle co-variation.

In the study presented in this paper we have tested relative leg strength with respect to balance control. The strength may also have an influence on parameters of gait. The easy way of improving the relative strength of legs is losing weight. The study on gait parameters after weight reduction treatment has shown positive effects on gait kinematics [17]. In our earlier studies [11] we have shown that the speed of locomotion and of rotation movements strongly correlated with the postural balance control ability. The findings indicate that the speed of locomotion and rotation movements can also be treated as contributors of the ability. An analysis of previous studies related to the balance control ability has shown that flexibility in attention switching, speed of initiation and execution of horizontal stepping movement in response to visual stimuli, postural muscles anticipatory preparation, strength and power of muscles, speed of locomotion and rotation movements may be considered as contributors to the balance control ability. The analysis has also shown that stepping up movements were less explored than horizontal stepping movements in the aspect of balance control contributors and fall risk predictors. The stepping up task activates explosive and dynamic strength to a higher degree than horizontal stepping tasks. The postural balance control ability measured on stabilograph also requires the activation of the leg explosive and dynamic strength to make necessary changes in the body position (correction movements) during the experiment. The verti-

cal stepping speed seems to be a better contributor to the postural balance control ability and predictor of the risk of falls than the horizontal stepping speed, because in the vertical plane the inertia of moving body did not hinder seniors to perform the movements with the maximum speed, while in the horizontal stepping task it would. In everyday motor activities the stepping up and down movements occur very often. People in an advanced age slow down the movements because they have less relative strength of their legs. Our study on age differences in strength has proved that and shown large differences in the speed of stepping up movements (relative leg strength) between young and elderly subjects [20].

The aim of the study presented in this paper was:

- to show a simple, computed method of testing the relative leg strength in a way related to everyday activities,

- to examine whether the relative strength of legs in stepping up movements is related to the balance control ability in seniors.

We have hypothesized that there is a strong relationship between relative strength of legs and a postural balance task performed on a force platform, and therefore the strength can be treated as a contributor to the balance control ability. 9 seniors (7 female and 2 male) with the average age of 69.8 years ($SD = 5.7$) participated in the study. The subjects had not reported any fall events during the last year. The participants of our study could walk independently and did not have any neurological and movement disorders. Subjects were volunteers and were not paid for participation in the study.

2. Materials and methods

A fundamental human motor and psychomotor efficiency timer and a standard stabilograph were used in the study presented. The timer consisted of a computer, a controller and some measurement stations [10]. To test human motor and psychomotor efficiency, the timer enabled applying different measurement stations [12]. In this study we have used the leg and arm strength measurement station (figure 1), which enables testing the relative strength of arms in hanging on a bar and in supporting oneself on the hands on two parallel bars as well as the leg strength in stepping up movements on the step-box. The part of the timer used to test leg strength consisted of 4 tactile leg sensors that were located on two platforms (figure 1).

One platform was placed on the floor level and the other 30.5 cm (12 inches)* above the floor on a step-box. Each leg sensor consisted of two resistance circles. Subjects performed stepping up movements with the left and the right leg in response to two audio-visual signals (stimuli) that were presented in the instant of putting both feet on the sensors on the upper and the lower platforms. The strength of legs was measured indirectly by movement total time (MTT) of the other leg than the one which was used to step up on the step-box as the first one. The time was measured from the instant of putting the first leg on step-box leg sensor till putting the second leg on the other sensor on the box. Thus the right leg movement total time (MTTR) reflected the total strength of the left leg and respectively MTTL showed the total strength of the right leg. Total strength consists of explosive and dynamic strength. The explosive strength is responsible for initiating, while dynamic strength for performing the straightening of the leg which was put on the step-box as the first one. Subjects were asked to perform stepping up and down movements as fast as possible. To protect subjects against falls, during the experiment they could support (not keep) their hands on handrails (parallel bars). In these conditions of safety, the tested seniors could perform the stepping up movements with the maximum speed without being afraid of the inertia effect in fast performing of the tested movements, which could cause an increase in the risk of falls.

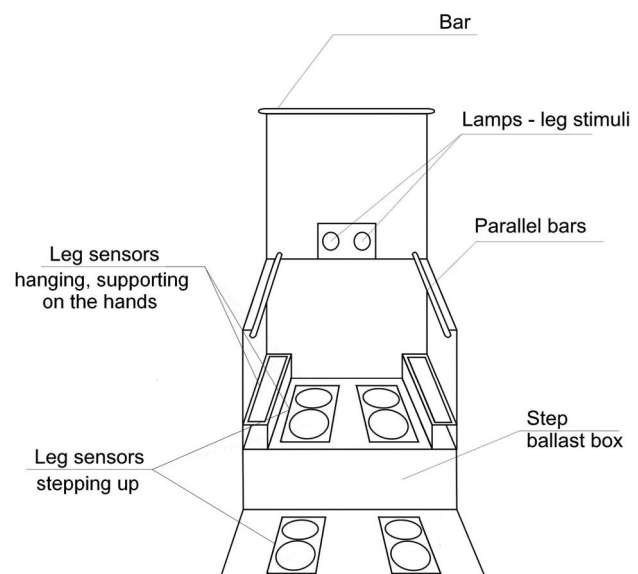


Fig. 1. The measurement station of the relative strength of legs and arms fundamental for everyday activities

* We began our work on the test in the USA at Arizona State University.

The stabilograph consisting of a computer and a tensometric platform was used to test the balance control ability. The ability was tested on the basis of the length of the center of pressure oscillation line (COPL) in the standing position on the measurement platform with covered eyes for 30 seconds.

One way Anova was used to test statistical significance of difference between the total stepping up movement time (total strength) for the left and the right leg. The statistic hypothesis that the measures of leg strength (MTTR and MTTL) and the measure of motor control ability (COPL) are independent was examined on the basis of Pearson's correlation for $p < 0.05$.

3. Results

The average (M), minimal (Min) and maximal (Max) values and standard deviation SD for the factors tested are presented in table 1. The matrix of Pearson's correlation coefficients between the factors examined is shown in table 2. We have found a strong and statistically significant correlation between total movement time (MTT) for the left (0.77) and the right (0.83) leg and the index of postural sways (the length of the center of pressure oscillation line COPL). Our study has also shown a very strong correlation (0.95) between MTTR and MTTL, which indicates that the subjects who have a strong or weak left leg have also a strong or weak right leg.

Table 1. The total strength of the left and right leg measured by the total (MTTR, MTTL) time and length of center of pressure oscillation line (COPL)

	Left total leg strength	Right total leg strength	COPL
	MTTR	MTTL	
M	1.697	1.768	300
Min	1.381	1.465	138
Max	2.054	2.128	438
SD	0.224	0.225	109

MTTR, MTTL were measured in seconds, while COPL in mm

The difference between the strength of the left and right leg tested on the basis of one way Anova has occurred and we have found this difference statistically significant for $p < 0.023$. These findings indicate that the subjects tested have demonstrated their left leg to be stronger than the right one.

Table 2. The matrix of correlation between the total strength of the left and the right leg measured respectively by total (MTTR, MTTL) time and length of center of pressure oscillation line (COPL)

	Left total leg strength	Right total leg strength	COPL
	MTTR	MTTL	
MTTR	1	0.95	0.77
		$p < 0.001$	$p < 0.042$
MTTL	0.95	1	0.83
	$p < 0.001$		$p < 0.01$

4. Discussion

A very important task for researchers is to prove what factors could be treated as the contributors to the balance control. It was reported that flexibility in switching attention [24], [32], [23], the speed of reacting in horizontal stepping [20], [7], [30], [28], anticipatory postural preparation [22], [1], the strength and power of muscles [25] tested in conditions not related to everyday life might be treated as such contributors. In the study presented we have shown that relative strength of legs examined in conditions similar to everyday activities (stepping up movements occur often in everyday life) can also be treated as balance ability contributor in seniors. The study presented has shown differences in the total leg strength between the left (MTTR) and right (MTTL) leg in stepping up movements in seniors, too. The obtained results indicate that the lateralization in leg strength occurs in the population of older people. Our study is in agreement with SKELTON and colleagues [25] research, which has also shown asymmetries in leg strength in seniors.

We have found a strong correlation between the total strength of legs and the index of balance control ability (COPL) in older people. The results support the research hypothesis which we have put forward in this study. The statistic hypothesis of independence of leg strength and balance control ability was negatively verified (rejected) for $p < 0.042$ and $p < 0.01$ for the right and the left leg, respectively. The obtained results indicate that the speed of stepping up movement, which we have treated as an indirect measure of relative leg strength can be treated as a contributor to the balance control ability. These findings suggest that by improving the strength, seniors can improve the balance control. The improvement may cause an increase in the safety and the conviction in performing fast daily motor activities requiring stepping up move-

ments. The results of our study are in contrast to the findings by SCHLICHT and colleagues [21] that suggest that strength training does not enhance standing balance or sit-to-stand performance in older adults but that it may improve walking speed. The aging process causes a decrease in the speed of contraction of the muscle [15], which can result in a slower speed of stepping up movements. We have proved in this study that the decrease in the speed also causes a decrease in the posture balance ability in seniors. The decrease in this ability is one of the most important limitations in motor behavior of people in advanced age [18], [29]. It is commonly known that the disturbance of balance is the main symptom of aging impairment and it may result in falls in fast performing complex movement [4], [33], therefore, elderly people perform the movement slowly. Slow performance of movements does not activate the white fibers in muscles. It results in losing the fibers as a consequence of nature law that unused human organs disappear. Older people who lost the white fibers are not able to perform movements fast, the fibers produce fast movements. It is the main reason why seniors should perform everyday movements fast and produce high strength of the leg but also arm muscles. The forms of motor activity that require the high speed of movements or high strength of muscles should be treated as “motor medicine” which protects older people from balance control impairment. The presented strength approach to balance control ability impairment can be treated as a theoretical basis for different exercise and intervention programs directed towards improving the balance control ability by developing leg muscles strength. Our previous study in this field [11] showed that the speed of locomotion and rotation movements strongly correlates with the postural balance control ability. The recommendation of the study was that older people should perform the locomotion and rotation movements fast. The previous study can be treated as a scientific basis of jogging, Nordic-walking and dancing intervention programs in seniors. The way of improving balance control by fast performing complex movement is supported by study of CROMWELL et al. [5], who have shown the positive influence of Tae Kwon Do exercises on balance and walking ability in older adults.

We think that complex movements performed only in the horizontal plane may not activate all the muscles that are engaged in vertical stepping. We also perform stepping up movements very often in daily life (stepping up the stairs, getting on the train, bus, etc.); therefore, we also need large strength of legs to perform the movement sufficiently fast and with full balance control, which would reduce the risk of falls.

The strong relationship between the balance control ability and the speed of stepping up movements found in the study presented indicates that the strength of muscles which produce the movement in the vertical plane determines the balance control ability. The results obtained show that stepping up stairs, step-box exercises, biking and hiking might be useful forms of motor activity to improve balance control ability in seniors and should be taken in consideration as important elements of intervention programs in seniors. The method of testing the relative leg strength presented in this study is part of a multidimensional test of human fundamental motor and psychomotor efficiency, which can be used in the public health system. LAMB and co-workers [9], who have conducted a study directed on elaborating a multidimensional test of fall predictors have also tested the strength of legs as a potential predictor of fall risk (contributor to the balance ability). This is also an important argument to test relative strength of legs in the public health system. The prevention is less expensive than the treatment.

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