



Quality of balance and pressure distribution beneath the foot during double-leg stance in young women

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Abstract

Introduction: One from the important preconditions for optimal performance of all physical activities is a good quality of balance. *Aim of Study:* The study is focusing to find out the effect of pressure distribution beneath the foot on the balance and to compare the quality of balance in physically active and inactive young women. *Material and Methods:* Subjects of our study were two groups of healthy young women. A: physically active women (n=28; age 21.5 years; physical activity 8.8 hour/week), B: physically inactive (n=28; age 22,0 years; physical activity 1.3 hour/week). Three balance test we carried out: double-leg stance, eyes open (EO) and closed (EC) for 30 second, one-leg stance (right, left) for 10 second. Pressure walkway (FDM system, fi. Zebris) was used for data collection. Parameters: COP_v: velocity of centre of pressure (mm/s), relative value of average pressure beneath the foot (%). *Results:* We found out that a physically active group of young women have significantly better results in all tests ($p \leq 0.05$). Both groups showed a similar tendency for significant deterioration of the results when elimination the support surface or the visual sensor in relation to the basic OE test. The differences in the distribution of pressures between the groups were significant in the M-L directions. Inactive women significantly more loaded the non-preferred leg and the rear part of the foot. Active women showed a more balanced stance in both directions, with a slight tendency to increase the loading on the front part of foot. *Conclusion:* It was confirmed that the group B has a partly worse characteristics of balance than physically active peers. The foot load strategy was less favourable for the group B; during EO. Only two interesting correlations were found in active women; between COP_v and ratio of feet load. Remaining correlations to COP_v were low.

Keywords: balance, physical activity, pressure, test, young women

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INTRODUCTION

The movement is a process that is connected by sufficient quality of the CNS, neuromuscular, vestibular, visual, and sensorimotor system or musculoskeletal system [1]. One from the important preconditions for optimal performance of the needed physical activities is a good level of balance [2]. Balance can be characterized as the dynamics of the postural control system associated with maintaining balance during quiet stance, walking and other physical activities [3].

The basis of balance is formed during the childhood and youth, approximately until the age of 17–20 and the ability to naturally maintain the required level of balance seems to be optimal at the ages ranging from 20 to 60 years [4]. During 7th decade of life, the quality of balance is starting to deteriorate due to aging [5,6].

The quality of balance is usually similar in healthy individuals. Most studies deal with the balance of elderly people and the patients [7,8]. In studies are compared older and younger age groups [5,9–11] or examine the influence of different external conditions on the quality of balance [12]. Fewer studies focus also on young age groups [7,12,13] or on the quality of balance in young adults with different volume of physical activities. Balance can be positively influenced by the adaptation to the physical activity, especially the adaptation to specific stimuli focused on improving coordination [13].

Balance testing is carried out in a variety of ways. Various stances, postures, tests of motor skills are used [2]. For up-to-date balance testing, force or pressure plates are currently used to determine COP, pressure, force, or spatio-temporal parameters [3]. COP monitoring mainly uses the average COP velocity, COP length, amplitude size [3,13]. When testing on a force or pressure plate, the most commonly used stances are double-leg stances with open or closed eyes with different leg positions or one-leg stances. Most authors use the time period of 30 s for tests of double-leg stance in baseline position with open or closed eyes [2,14]. For monitoring of one-leg stance, the most frequently used time was 5–30 s [11,15–18]. The quality of balance is based on a number of factors, including also the skills of proper position and load of lower limbs through different movements [19]. A good balance is needed as early as at a young age to form a sufficiently high basis for older age when is expected decline to lower level. But this quality must allow sufficient mobility to a high age. With a lower level of balance at a younger age, it is clear that with aging its quality drops prematurely below the level necessary to ensure a certain degree of mobility. Therefore, due to the sedentary lifestyle and predominantly sedentary occupations, it is necessary to be engaged in sufficient physical activities to maintain skills and balance at the required level.

The aim of this study was to find out whether we can reveal significant differences in the level of balance in young women with different levels of physical activity (PA) and how the balance is affected by individual foot pressure distribution or distribution on feet parts.

MATERIAL AND METHODS

Participants

This comparative study was performed in a laboratory with two groups of young women (Table 1). The first group consisted of women with low physical activity (N) and the second group were women with high physical activity (A). Participants were female students of Brno University of Technology who volunteered to participate in the research. The presented research included only healthy women without muscular, orthopaedic or neurologic problems, none of the subjects had consumed alcohol, or used medications that would depreciate our research. All subjects provided a written informed consent to participate in the study, which have been approved by the Ethics Committee of the Department.

Protocol

Laboratory research was carried out under standard conditions for all tested subjects. Three tests were performed to monitor the balance. Test 1: Double-leg stance, eyes open (EO), Test 2: Double-leg stance, eyes closed (EC), Test 3: One-leg stance, eyes open (R – on right leg, L – on left leg).

Table 1. Basic characteristic of the participants

Group		n	age (years)	height (cm)	mass (kg)	BMI	PA (hours /week)
B	Average	28	21.5	1.64	57.6	21.5	1.2
	SD		2.1	0.05	10.6	3.7	0.4
A	Average	28	22.0	1.70	67.4	23.0	8.8
	SD		1.8	0.06	11.3	3.6	2.0

SD - standard deviation

Prior to EO and EC tests, each participant was instructed to take a stance on the plate in the parallel position of their feet, shoulder-width apart, with arms akimbo. In the course of the test, each subject stood motionless with eyes focused on the marker (EO), which was placed 1.5 meters away on the wall in front of the subjects at the level of their eyes. The test consisted of three 30-second tests. Between each measurement, there was an interval of 30 seconds. The subjects carried out three measurements with eyes open (EO) and another three with eyes closed (EC). Between EO and EC tests, there was a 3-minute pause. Three trials were averaged.

For test 3 participants carried out repetitive stances on the right (R) and left leg (L). A stance on each leg lasted always 10 seconds and was repeated three times. Between each measurement, there was an interval of 30 second. Subjects took the standard position on one foot with arms akimbo, staring at the marker at the eye level at a distance of 1.5 m in front of the participant. After reaching one-leg stable balance position, recording was made. Subjects were instructed to stand as motionless as possible. Trials were discarded and replicated if a touchdown (the non-stance leg touching the ground) occurred during the trial. With the help of questionnaire, we collected the data on weight, height, age, and physical activities and health.

Instrumentation

The FDM system (fi. Zebris) was used. This system consists of a 3-metre long walkway with pressure sensors, on which the subjects walk, and a computer system. The record was performed at a frequency of 92 Hz. A pressure walkway enables a collection of data and also an analysis of stances. A range of measurements is 1-120 N/cm² with accuracy of $\pm 5\%$.

Parameters

COP_v - velocity of COP (mm/sec), P - relative value of pressure beneath foot or its part (%). The relative values of pressure distribution on the plate beneath both feet were evaluated in the EO test. Firstly pressure beneath right and left foot (direction M-L) and beneath the front and rear part of the foot (direction A-P). For the relative pressure distribution on the front part and rear part of the foot, the average of both legs was calculated. Pressure distribution beneath preferred (pr) and non-preferred (np) foot was also evaluated.

Statistics

Basic statistics (average, standard deviation, %), t-test ($\alpha=0.05$), substantive significance was reported with the help of Cohen size effect coefficient d ($d<0.5$ indicate small, $d=0.5-0.80$ moderate and $d\geq 0.8$ large size differences), Pearson product-moment correlation coefficient.

RESULTS

First part deals with the description of the results of the balance tests, second part deals with the pressure distribution beneath the foot during the EO test and the relationship between the pressure distribution and the COP velocity.

In both groups, the lowest COP_v was found in the EO test and the highest in the EC test. In all four balance tests, active women achieved a significantly lower COP_v ($p_{EO}=0.001$, $p_{EC}=0.033$, $p_R=0.044$, $p_L=0.002$) than physically inactive women. Also, when evaluating the one-leg stance on preferred and non-preferred legs, there were statistically significant differences between groups in COP_v ($p_{pr}=0.001$, $p_{np}=0.05$) in favour of group A. The size effect was large for all tests among the groups observed

($d_{EO}=1.09$, $d_{EC}=0.91$, $d_R=1.3$, $d_L=0.93$). With the non-preferred leg, the size effect was large ($d=0.96$), while with the preferred leg, it was moderate ($d=0.48$).

Both groups showed similar tendencies in EC, R and L deterioration of results compared to EO. The largest and statistically significant difference was always found in both groups between EO and EC ($p_A=0.000$, $p_N=0.011$). In one-leg stance tests (R, L) smaller differences were found out toward EO than for EC, but were always significant (group N: $p_{EO-R}=0.050$, $p_{EO-L}=0.007$; group A: $p_{EO-R}=0.000$, $p_{EO-L}=0.000$). The differences between the EC, R and L, tests were small and statistically insignificant in both groups ($p=0.072-0.314$). A large size effect between EO and all remaining tests was detected only in the physically active women ($d=1.48-1.81$). In the group of inactive women, deterioration was smaller, the size effects were moderate and small between EO and all remaining tests ($d=0.42-0.72$). Among EC and R, L tests, size effects for both groups were small or moderate ($d=0.17$ and 0.45). The differences between R and L leg were not significant in both groups ($p_A=0.337$, $p_N=0.174$, $d_A=0.1$, $d_N=0.6$), and similarly also between the preferred and non-preferred leg ($p_A=0.206$, $p_N=0.089$) and the size effect was weak in both groups of female students ($d_A=0.21$, $d_N=0.34$).

The pressure distribution on the lower limbs was evaluated using the relative values of pressure distribution beneath the foot on the plate during the EO test (%). The mean value of pressure beneath the feet or parts of the feet was in relatively large range in both groups. For group A, the range of mean relative pressure beneath the right foot was 44.7–54.7%, beneath the left foot 45.2–55.3%, beneath the front half of the feet 43.3–57.7%, beneath the rear half of the feet 42.3–56.8%. For group N, the relative pressure beneath the right leg was 46.0–52.3 %, beneath the left leg 47.7–54.0, beneath the front part of the feet 23.8–75.7% and beneath the rear part of the feet 24.3–74.2%.

Between the groups, significant differences in pressure were found between both the right foot and the left foot ($p_R=0.003$, $p_L=0.003$) and also beneath both the front or the rear part of the foot ($p_F=0.049$, $p_{Re}=0.049$). Size effects between the groups were large for the pressure beneath the right and left foot ($d_R=0.86$, $d_L=0.86$); for the pressure beneath the front or rear part of the feet, the size effect was only moderate ($d_F=0.52$, $d_{Re}=0.52$). In most of the female students of both groups, preference

Table 2. Results of balance tests

Group		EO	EC	R	L	pr	np
B	Average	6.37	8.95	7.46	8.31	7.45	8.18
	SD	2.68	4.33	1.68	2.37	2.40	1.63
A	Average	4.31	6.98	6.66	6.45	6.73	6.38
	SD	1.24	2.22	1.35	1.43	1.44	1.32

SD - standard deviation, pr - preferred leg, np - non-preferred leg

Table 3. Relative pressure beneath the feet at the EO test (%)

Group		R	L	F	Re	pr	np
N	Average	48.5	51.5	46.3	54.0	51.0	49.0
	SD	2.0	2.0	11.8	11.8	02.3	02.3
A	Average	50.4	49.6	50.7	49.3	49.4	50.6
	SD	2.4	2.4	5.0	5.0	2.3	2.3

SD - standard deviation, pr - preferred leg, np - non-preferred leg

Table 4. Correlation of representative variables

Group	$COP_v - R/L$	$COP_v - F/Re$	$COP_v - p/np$
A	0.709	0.109	0.748
N	0.006	0.014	0.017

Legend: R/L rate of load percentage of right and left foot; F/Re rate of load percentage of front and rear part of foot; pr/np rate of load percentage of preferred and non-preferred foot

was given to the right lower limb (N=86% and A=95%); however, in the EO test, groups A and N demonstrated a different strategy for lower limb load. Group N showed a significantly higher pressure beneath the left foot ($p=0.000$, $d=1.5$) and also a significant difference in pressure was found between preferred and non-preferred leg ($p=0.004$, $d=0.85$). The pressure beneath the front and rear part of the feet was significantly different in N in favour of the rear part ($p=0.015$), size effect was moderate ($d = 0.68$). Group A demonstrated more balanced stance with a slightly higher pressure beneath right foot, which was the preferred one for most women, but the difference was not significant ($p=0.131$, $d=0.33$). A comparison of the pressure beneath foot of the preferred and non-preferred leg also revealed no significant difference ($p=0.293$, $d=0.14$). Physically active women loaded again relatively equally both parts of the feet in the A-P direction with very little tendency to increase the front part of feet, therefore, the difference was not statistically significant ($p=0.181$) and the size effect was weak ($d=0.28$). The ratio of pressures beneath the feet or their parts in A is close to the balanced state, while in N, a greater imbalance is evident from the coefficient.

From these results, we tried to determine the relationship between the pressure distribution beneath R, L and preferred, non-preferred feet to COP_v (Tab 4). Relationship was calculated with the help of the ratio of the relative values of pressure distribution R/L, pr/np and F/Re to the COP velocity. From the table, it is evident that significant correlations were found only in group of active women between COP_v and the ratio R/L ($r=0.709$) and p/np ($r=0.748$). Remaining correlations do not indicate significant relationships between the pressure distribution and COP_v .

DISCUSSION

The main objective of the study was to find out differences in the quality of balance between physically active and inactive young women and the influence of pressure distribution beneath the foot on COP_v as an important precondition of a stable position. Balance is one of the important skills that help us to keep an individual's mobility at an elderly age so that elderly people remain self-sufficient and active even in the aging process [2]. Therefore, it is important to study changes in preconditions ensuring the required level of balance in the younger adulthood. Balance naturally develops to approximately 18 to 20 years [4], maintaining individual quality in the following periods of life and after 60 years of age its level is decreasing [2]. At present, the lack of physical activity in a large part of the population affects the quality of physical fitness in a negative way and also the quality of skills [20]. Therefore, we try to investigate the balance characteristics and the influence of regular training with non-specific exercises on balance quality in various social and age groups. In our group (young adulthood), we can observe the beginning of differences in the quality of balance in both basic and more difficult posture situation in favour of those individuals who are physically active. The positive influence of intervention training programs on the quality of balance was also confirmed by various authors [8].

The greatest difference between the groups was found in the EO test (47.8%), which is the baseline and standard test for the evaluation of the balance quality and the postural steadiness in all age categories [6,9]. This result documents the fundamental difference between groups in the quality of balance needed for everyday life because the position in the test is similar to the initial position for carrying out many daily routine activities under the usual conditions. In the EO test, group N showed the results similar to other studies [7,9], while the group A was mostly better than the results from these studies. It also shows on higher quality of balance skills for group A.

The difference between the groups in the EC test was smaller (28.2 %) and active women were again significantly better. This is also consequence of better level of motor skills. At this age, in healthy young women, this test is not a common daily situation, but it shows the quality of the vestibular and sensorimotor system sensors, which must compensate the visual sensor elimination to maintain the necessary balanced position [6,21]. The influence of quality skills, which were developed and maintained through structured movement activities, is probably greater for a test comparable to common conditions for single movement task (EO) than for more demanding tests where we found a smaller difference between the groups (EC, R, L). It is interesting; we expected rather increasing of differences as consequence of higher volume physical activity. Compared to other studies, women of

group A are significantly better in the EC test than the studies with a peer [10] and group N achieved similar results to these studies. Other authors report rather worse results [12,14].

Differences between the groups in the one-leg stance test were significant and also size effect was large (R 12.0%, L 28.8%, preferred leg 10.7%, non-preferred leg 28.2%). Decrease of the supporting surface in everyday moving is usual; therefore, the result is important for assessing the ability to keep more demanding postures on one leg or to transfer weight from one leg to the other; this includes number of routine daily activities and also gait. This test is more demanding for both the muscular strength, skills, and also for coordination because the movement structure is more difficult [18], so it is logical that the differences between A and N in the non-preferred and the left leg are greater. These differences in the non-preferred leg may be associated with a lower level of movement skills or a lower level of motor learning in group N, which is usually associated with low physical activity in healthy individuals [20]. The absolute values of COP velocity at one-leg stance in both groups of young women were significantly better compared to other studies [16,17] or similar [22].

The results of four used tests support the opinion that even in younger adulthood, the quality of balance can differ. Physically active women have a better level of balance, and it is clear that only the natural predispositions of inactive women may not be sufficient to achieve a similarly high-quality result. Although, the regular physical activity of the group of active women was focused on a complex conditioning training, not specifically on training the skills or balance, group A documented very good results, also with comparison to another studies above mentioned. Group A undertook the training on average 3–4 times per week, one training session for about 1.0–1,2 hours. Rest time of physical activity they carried out as no structured activity. The exercise was focused on developing and maintaining general fitness in both the gym and the field. Group N did not exercise, they carried out unstructured physical activity only. It is possible to confirm the results of other studies that even the general fitness training is suitable for achieving better results in balance tests [13]. Regular training simultaneously improves the perception, sensitivity and activity of systems and sensors involved in maintaining optimal body position and coordination of all their parts [21]. Although the effect of physical activities and regularly practising on the quality of balance is usually investigated in higher age categories or in the case of deteriorated health condition [23,24], our study also confirms better results for a healthy women in the third decade of life. A higher quality of balance in group A is also confirmed by a similar result in EO test in group N and EC test with visual limitation in group A. Difference was statistically insignificant and size effect was small ($p=0.370$, $d=0.13$). A comparison of our groups with the results of other studies shows a higher quality of balance skills for group A than shows the common population; group N proves a comparable level to their peers.

In the internal group evaluation, similar tendencies in differences among tests were found in both groups. Differences among EO test, where there is no limitation, and the remaining tests with different types of limitations, were always significant in both groups. Other research also confirms that EO test modifications cause a significant deterioration of COP_v either in healthy and unhealthy individuals or in older age groups [7-10,12]. The results of the remaining tests (EC, R, L) were similar in both groups, with no statistically significance and small size effects. This suggests that, in our groups, the limitation of smaller surface combined with a more difficult one-leg stance or the visual limitation have a similar effect on the quality of the balance. If we compare the EC, R, L movement characteristics, a double-leg stance, is easier than one-leg stance. In a one-leg test, the movement structure is more difficult, we need higher quality of coordination and muscle strength [25]. In EC, the visual sensor is compensated by vestibular and sensorimotor sensors at the cost of balance quality deterioration. This deterioration is individual and increases with age [2,5,6]. Although the absolute deterioration in the results between the EO and EC tests was similar in both groups, group N represented a lower relative difference (40.5 %) than group A (61.9%). Here we expected the opposite result and a minor absolute and relative deterioration in women of good condition, which was not confirmed. This could have been due to a very good result in EO for group A. Although both of our groups showed rather better results in both the EO and EC tests than were those in other studies, we found a greater deterioration in the EC test than e.g. [12].

Results of one-leg test also showed a significant deterioration to the EO test in both groups (N for R 17.1%, L 30.4%, A for R 54.5%, L 49.6%). Compared with the EC test, both groups showed a better result, but the differences among EC, R, L were insignificant. COP_v for the stances on the right,

left, preferred, or non-preferred leg were comparable in each group without significant difference, which is a positive finding. Other studies also confirm that balance skills are on the right or left, preferred or non-preferred lower limb without significant differences [15,16,26]. This kind of balance is important in healthy people for basic physical activities and mobility, such as symmetrical gait or stances and postures on both legs, because do not create predispositions for the development of disbalances or other health problems of the locomotor system. Unlike with seniors where the one-leg stance shows a significant deterioration compared to the above-mentioned tests [11], in our young women, the outcome of a one-leg stance test was comparable with that of EC. When standing on one leg, the results are also affected by other predispositions, such as a level of coordination, muscular strength, ability to achieve a correct position on a smaller supporting surface, ability to actively recruit the ankle to maintain a correct balance position, overall quality of movement skills [18,27]. The quality of one-leg balance can be influenced by training [24], with which we agree, although e.g. [27] did not find this change after completing the intervention program. It should be remarked that the comparison of EC test and the one-leg stance is difficult because each of these tests is based on a different type of limitation. On the other hand, it allows evaluating and comparing predispositions for balance from different angles of view [21]. Therefore, it is appropriate and necessary to use both tests, because changes or differences can show the causes of negative process and what to focus on when maintaining or improving the balance.

The balance is influenced, in addition to the quality of the sensors, by a number of other factors and predispositions, among which include the optimal pressure distribution beneath foot [19,28]. Therefore, we evaluated the differences in pressure distribution in M-L and A-P directions and we searched for the relationship between the pressure distribution in the EO test and COP_v , which can help to express the quality of balance.

When evaluating the pressure beneath the feet in the mediolateral (M-L) and antero-posterior (A-P) directions, we found different strategies for pressure distribution in EO. In the M-L direction, the pressure beneath both feet in A group is more equally distributed. This means better spread the body weight on the right, left, preferred or non-preferred leg. A better distribution of pressure on both legs may be the result of better movement stereotypes in trained women because the accomplishment of general and specific movements is based on better skills, coordination, movement automation, more optimal and more effective weight distribution over the lower limbs to create support on the base [24,25]. In the end, this means even a more symmetrical load of the whole body, which counteracts the development of disbalances or onset of other problems with the locomotor system [25]. In M-L direction inactive female students showed a higher load of left foot, which is the non-preferred leg for most of them. This is an interesting finding because they achieved a better result in the one-leg test for R (in COP_v) and we supposed that this should also be reflected in the result of the M-L direction pressure distribution during EO. The reason is difficult to explain; however, it may be the result of a greater load on the rear part of the foot in this group, a less strengthened body in untrained individuals with less muscular strength, lower quality skills which can cause greater variability in movement and worse postural steadiness.

In the A-P direction, active female students proved to have a more advantageous posture at EO with a slight tendency to increase the load on the front part of the feet. We consider this tendency to be more advantageous, more effective and more natural. It means more active ankle recruitment in the posture while keeping balance. It is beneficial for active and correct on-time start of movement in all physical activities. We think that a more favourable pressure distribution beneath foot in the A-P and M-L direction is also the result of regular physical training, which improves the quality of skills in general as well as the required automation of the needed movement structure [20]. Regular training further improves the economy of the movements and the ability to maintain most effective position during various stances and positions [25].

Higher pressure on the rear part of foot with N group partly eliminates the ankle activity, which help to maintain a stable position. More work and greater movement of the upper body (COP) is needed to maintain balance. It could be a more comfortable stand, but caused more difficult start of intended movements or maintain a good balance. We suppose that inactive women are taking a less favourable position with less balanced pressure distribution beneath both feet in A-P and M-L direction during EO. More effective stand is characterized by a more balanced distribution of the load

on both legs with slight predominance of load on the front part of the feet or at least a very balanced load of the front and rear part of the feet. The reason for worse position of N may be a worse movement stereotype (non-fixed movement patterns), lower quality of basic skills, worse overall coordination even of the individual parts of the body, worse automation of movement and postures, less muscular strength that causes a worse posture.

Despite a relatively small number of participants in our research, we tried to find out possible relationships between the pressure distribution beneath the foot and COP_v in the EO test.

We supposed that it is possible to find a strong relationship between the pressure distribution beneath foot and COP_v because a regular physical activity improves skills quality, muscle strength, strengthened body and there are also preconditions for a better balance [13]. The significant correlations were found only in the group of physically active women between COP_v and pressure distribution in M-L direction. These relationships points to a lower COP_v with a more balanced pressure distribution in M-L direction in this group. This is more advantageous for keeping a stable balance position, even for initiation of the movement in different directions. This information we use in further study with a larger number of participants and a larger age range. We also expected significant correlations between the pressure distribution on the front and rear part of the feet, which is an important precondition for the on time initiation of high-quality movement in sports. In particular, the load transfer to the front part of the feet also means a greater flexibility to maintain the balanced posture. Higher pressure on the front part of the feet allows for more active ankle involvement to maintain balance. Most of the other correlations were weak. A similar level of correlations was presented, for example, by [15,29].

CONCLUSION

A better level of balance was demonstrated for the physically active women in all the tests that were used. A positive relationship between pressure distribution beneath the feet of both legs and COP_v was confirmed only in the group of physically active women. A more favourable position of active women was found in terms of pressure distribution beneath the foot, which was more balanced in both directions (M-L, A-P).

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