



Dynamic Single-Leg Balance Tests of Physiotherapy Students: A Comparison of Body-Active Weight Shift Test and Two Sudden Disturbance Tests

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Abstract

BACKGROUND: Balance is essential to maintain and stabilize the transition from static to dynamic posture. The human body can maintain the center of gravity within the base of support and to process input from vision, the vestibular apparatus, and the somatic senses.

AIM: The research aimed to check the correlation of the active body-weight shift test (Y balance test [YBT]) and two sudden perturbation tests in physiotherapy students.

METHODS: In a cross-sectional study, a descriptive research design was used. Twenty-nine healthy adults (14 men and 15 women) with a mean age of 23.6 ± 6.3 were tested using the active body-weight shift test and two sudden perturbation tests. A descriptive statistical analysis using correlation coefficients was performed.

RESULTS: Our subjects' average values of the test results meet the normative values. There is a correlation between the YBT test and the crossover hop test in the anterior ($p < 0.01$), posterior-medial, and posterior-lateral directions ($p < 0.05$), and the triple-hop test forward in the posterior-medial and posterior-lateral directions ($p < 0.05$), and anterior direction ($p < 0.01$) for the left extremity, except for the anterior direction to the right. With the right extremity, there is a correlation between the YBT test and the crossover hop test and triple-hop test forward in the posterior medial ($p < 0.05$), the crossover hop test in the posterior medial and posterior lateral to the left ($p < 0.05$), and the right ($p < 0.01$), but no correlation in the anterior direction in either of them.

CONCLUSION: The data of all physiotherapy students in our study meet the normative data, and no difference due to gender has been observed. There is a correlation between the active body-weight shift test and sudden perturbation tests with or without lateral movement for the left extremity, but not for the right extremity. We can assume better results when standing on an undominant limb, which can lead to insufficient support when standing on a dominant limb. What should not be the case in providing patient safety.

Edited by: Sasho Stoleski
Citation: Tivadar BK, Kotnik P. Dynamic Single-Leg Balance Tests of Physiotherapy Students: A Comparison of Body-Active Weight Shift Test and Two Sudden Disturbance Tests. Open Access Maced J Med Sci. 2024 Jun 15; 12(2):322-329. https://doi.org/10.3889/oamjms.2024.11896
Keywords: Balance; Dynamic stability; Physiotherapy students
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Received: 17-Mar-2024
Revised: 26-Mar-2024
Accepted: 08-April-2024
Ahead of print: 25-Apr-2024
Copyright: © 2024 Blanka Koščak Tivadar, Petra Kotnik
Funding: This research did not receive any financial support
Competing Interests: The authors have declared that no competing interests exist
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Introduction

The main objective is to highlight the complexity and diversity of balance assessment by outlining the nine components evaluated in balance. Balance nine components are postural stabilization (body and limbs), dynamic stabilization during movement, functional limits of stability, muscle capacity and coordination required to maintain posture and balance, sensory interaction processes, vertical perception, postural adjustments in advance, an appropriate balance response to perturbation, and the effects of cognitive processes [1]. Most standardized assessment protocols, 66 already described in 2015, evaluate three to five components of the balance-mentioned above components. The most common tests used to test dynamic balance are active body-weight shift tests, functional tests, unstable base of support tests, and sudden perturbation tests [2], [3], [4], [5], [6]. Due to the many assessment protocols and components of balance, it is often difficult to choose the proper test for evaluating balance.

Several things should be considered when testing balance. Balance in humans requires coordinated use of the somatosensory and vestibular systems, as well as visual information [7]. Although balance can be static when the body is at rest or dynamic when the body is constantly in motion, it always involves movement around the center of mass [8], with simultaneous body stability during movement [9]. Moreover, more than good static balance is needed to ensure sufficient dynamic balance. Therefore, assessing dynamic balance could provide more reliable information for daily life [10]. Establishing and maintaining balance and the ability to control posture with minimal sway [11] are necessary for performing daily activities [12]. Postural balance is ensured by appropriate patterns of muscle activations that maintain the body's center of gravity within a safe limit above the base of support or return it above the base of support after perturbations [13], [14]. In this case, equilibrium reactions are triggered by shifting the center of pressure of the ground reaction force within the base of support; the angular amount of the body around the center of mass of the support may change, or a new base of support may

emerge [15]. In addition to synergistic muscle function, good stability also requires the proper functioning of the central nervous system and the three major subsystems: somatosensory, vestibular, and visual [8], [16], [17] about the task and the environment [18]. When a balance disorder occurs, the return to a stable position is facilitated by three movement strategies: the ankle strategy, the hip strategy, and the step strategy [19].

Considering different impacts on balance and possible balance disorders, we decided, for the purpose of our research, to use three dynamic tests: the active body-weight shift test (Y balance test [YBT]) and two sudden perturbation tests (triple-hop distance test [THD] and triple crossover hop distance test [TCHD]). In the case of a one-legged stance, balance is controlled by shifting the center of pressure of the ground reaction force, moving the body holistically, and coordinating balance control mainly through coordinated muscle activity in the hip, knee, and ankle regions [20], [21], [22], and through muscle tone high enough to support the body against gravity and low enough to allow selective movement [1].

Based on these data, the aims of the present study were to test the dynamic single-leg balance of physiotherapy students: (1) to compare data with normative values; (2) to elucidate the correlation between the triple crossover hop test and the YBT; and (3) to elucidate the correlation between the triple-hop test and the YBT. We hypothesized that the data of physiotherapy students will meet the normative data and that there is a correlation between the triple crossover hop test and the YBT and a correlation between the triple-hop test and the YBT. The stability of physiotherapists is necessary to ensure patient safety. Balance is essential as the active body weight shifts and sudden perturbation since the patient can lose their balance. Including tests as an inclusion criterion for becoming a physiotherapist would be proper.

Methods

This cross-sectional study was conducted to evaluate the dynamic balance on one leg in physiotherapy students at the University of Novo Mesto and the Angela Boškin Faculty of Health Care Jesenice in April and May 2023. The main criterion for inclusion in the study was that the students of the Faculty of Health Sciences, University of Novo Mesto, and of the Angela Boškin Faculty of Health Care are enrolled in the higher education professional study program of physiotherapy, and the exclusion criterion for the research was the presence of a lower extremity injury. The Commission for Developmental Research of the University of Novo Mesto, Faculty of Health Sciences (number FZV 336/2020), and the Commission for Scientific Research and Development of the Angela Boškin Faculty of

Health Care (number 10/03-3/2021-MF) confirmed the ethical suitability of the research.

Subjects

Physiotherapy students were invited to participate in a study voluntarily. Among the 37, 29 healthy physiotherapy students decided to participate in the research. Women comprised 59% of the group, and men comprised 41%; they were between the ages of 18 and 42, with an average age of 23 ± 6.3 years. The average body mass index was 23.7 ± 3.2 (Table 1). The subjects entered the study voluntarily and provided written informed consent before data collection. All participants were informed about the potential risks and benefits of research and followed the design, protocol, and inclusion criteria. No participant was excluded from the study.

Table 1: Participants' characteristics

Characteristics	Value	Percentage
Age		
Mean \pm SD	23 \pm 6.3	
Sex		
Female	20.5 \pm 5.7	59
Male	25.1 \pm 6.8	41
BMI	23.7 \pm 3.2	
BMI		
Women	22.3 \pm 2.8	
Men	22.4 \pm 3.1	

BMI: Body mass index.

Procedure

An active body-weight shift test was performed to evaluate neuromuscular control [9], [23], [24], [25], [26]. In the study, we used the YBT to evaluate the participant's ability to maintain balance on one leg while reaching out with the opposite leg as far as possible in three different directions. The test is a highly representative dynamic balance test for healthy, active people, and patients [10]. The test was performed with open eyes, barefoot, and standing on straps attached to the floor, with the posterior directions positioned 135° apart from the previous one and 90° between them. The test was successful if they could maintain a single-leg stance, with the heel of the standing leg on the floor without lift. No touchdown was allowed with the reaching limb, and the hands had to stay on the hip. Each participant practiced 6 times with each lower limb in three directions before the actual test. The maximum reach was measured at the point where the most distal part of the foot touched the tape [27], [28]. During the sudden perturbation test, we conducted two tests: THD and TCHD. Both tests are useful tools to evaluate the functional capacity and lower extremity performance of individuals [29]. The THD test and the TCHD test are similar protocols used to assess lower limb function and performance. In THD, each participant performed three consecutive single-legged jumps aimed to achieve the maximum possible distance in the forward direction. In TCHD, each participant performed three consecutive

jumps by hopping forward, crossing back and forth, and trying to achieve the maximum possible distance in the forward direction. In both tests, hopping was performed barefoot and over a 15 cm wide and 6 m long line. Before the start, the participant placed the fingers of their foot at the beginning of the tape and on the side of the tape that corresponds to the first of the three jumps. In the case of the TCHD test, if the tested leg was the right leg, the subject was positioned on the left side of the tape. The distance from the beginning of the tape to the last contact of the heel with the ground was measured. All jumps were performed on the same leg without any pause, except for the controlled final landing. Stepping on the tape markers was not allowed. The participants kept their upper limbs on their hips, and on the last landing, they had to remain still for at least 1 s. Each participant completed three jumps with each leg, and the best result of the three was considered for analysis [30].

Statistical analysis used Microsoft Office Excel and Statistical Package for the Social Sciences 28.0 was used to process the data. Correlation coefficients were calculated, and the results were presented in tables and graphs and interpreted descriptively.

Results

Based on the results presented in Table 2, it can be concluded that all the participants' data meet the normative data in all single-leg dynamic tests.

Table 2: Participants' and normative DATA for YBT, TCHD, and THD

Variable	Limb	Sex	P DATA	N DATA
YBT AN	L	F	71 ± 8.8	70 ± 4.3
		M	76 ± 8.7	73.5 ± 83.5
YBT AN	R	F	70 ± 9.8	70 ± 4.1
		M	73 ± 110.4	73.1 ± 8.5
YBT PM	L	F	96 ± 114.9	92.9 ± 7.3
		M	105 ± 15.2	107.08 ± 8.7
YBT PM	R	F	96 ± 111.1	93.7 ± 7.3
		M	101 ± 11.4	104.2 ± 8.4
YBT PL	L	F	101 ± 12.5	92.8 ± 9
		M	112 ± 12.3	105.3 ± 11.6
YBT PL	R	F	101 ± 11.8	92.3 ± 8
		M	109 ± 12	105.00 ± 10.00
TCHD	L	F	363 ± 102	367.3 ± 53.0
		M	490 ± 109	493.2 ± 71.5
TCHD	R	F	354 ± 109	368.0 ± 49.0
		M	474 ± 116	493.2 ± 64.9
THD	L	F	377.6 ± 114	397.9 ± 45.6
		M	513 ± 106	542.4 ± 62.9
THD	R	F	400.6 ± 102	410.02 ± 45.2
		M	535 ± 112	546.1 ± 58.1

YBT AN: Anterior reach direction, YBT PM: Posterior-medial reach direction, YBT LM: Posterior-lateral reach direction, TCHD: Triple crossover hop distance test, THD: Triple-hop distance test, L: Left limb, R: Right limb, P DATA: Participants' data, N DATA: YBT normative values according to Alnahdi *et al.* [31], TCHD and THD normative values according to Haitz *et al.* [6].

According to the results presented in Table 3, there are correlations between THD and YBT and between TCHD and YBT. In all participants, there is a correlation between the TCHD, YBT PM, and YBT PL in all directions. There is also a correlation in YBT AN with a left limb, while in the anterior direction of YBT with the right limb, there is no correlation in either lower limb.

Moreover, there are no correlations between any other movements.

Table 3: Correlation between YBT and TCHD, and YBT and THD

Test	Limb	TCHD		THD	
		L	R	L	R
YBT AN	L	0.452*	0.440*	0.492**	0.308
YBT AN	R	0.002	0.044	0.126	0.082
YBT PM	L	0.576**	0.553**	0.703**	0.565**
YBT PM	R	0.534**	0.517**	0.623**	0.492**
YBT PL	L	0.640**	0.630**	0.705**	0.612**
YBT PL	R	0.595**	0.554**	0.608**	0.450*

YBT AN: Anterior reach direction, YBT PM: Posterior-medial reach direction, YBT LM: Posterior-lateral reach direction, TCHD: Triple crossover hop distance test, THD: Triple-hop distance test, L: Left limb, R: Right limb, *p < 0.01, **p < 0.05.

Discussion

The main purpose of the research was to evaluate the dynamic balance of physiotherapy students standing on one leg. Our key findings are as follows: (1) physiotherapy students have achieved the normative values; (2) there is a correlation between performing dynamic tests without lateral movements only in some directions; and (3) a correlation between performing dynamic tests with lateral movements exists only in some directions. To the best of our knowledge, this is the first study to examine dynamic single-leg balance, including the active body-weight shift test and sudden perturbation tests. Other authors have compared the correlation of YBT, triple jump, and cross jump with other components but not with each other. We can conclude that our students have proper balance according to normative data, but not according to different balance strategies in every direction. Due to ensure patient safety, the balance should be maintained independently to plane or perturbation.

We confirmed our first hypothesis that the data of physiotherapy students will meet the normative data for all the tests used in the study. Twenty-nine healthy students with an average age of 23 ± 6.3 years and an average body mass index of 23.7 ± 3 participated in the study. All students achieved the normative values on the YBT test in all directions, whereas they scored slightly below average on the THD and TCHD in both sexes. As expected, since our students were without injuries or pathology, they all met the normative values in YBT. The YBT test checks dynamic postural control in healthy patients and patients with various lower extremity injuries, such as chronic ankle instability, anterior cruciate ligament, and patellofemoral pain syndromes [10]. Because the test requires little equipment and is time-efficient, it is a very economical [10], [32], [33], feasible, and widely used tool [33]. It is used in different populations and is a valid and reliable test for assessing dynamic balance and postural control capacity [30], [34], [35]. Johnston *et al.* [16] cited the YBT as one of the most used clinical dynamic balance assessments. The test effectively predicts a 2.5-fold higher likelihood of lower limb injury when the difference between the two

lower limbs in forward reach is 4 cm or more [36]. When evaluating changes, an increase or decrease of 5.87%, 7.84%, and 7.55% or more in AN, PM, and PL denotes a change [37]. Dynamic balance is an essential component of motor skill development [9]. Several studies have confirmed that poorer performance on a dynamic balance test is associated with an increased risk of injury [38], [40], [39], [56].

There was a slight difference in the results of our study when comparing them to the normative data according to gender. The women in our study performed better in all three directions compared to the normative data, while men were better only in two directions (AN and PM), while, in PL, they did not meet the normative data. Even though there can be some differences according to sex in performing the YBT test and men can be better in all three directions [41], some studies found better performance in men [42], and some did not find any differences [43]. Kramer *et al.* [44] examined the relationships between mobility, dynamic balance, and physical performance in secondary school male and female athletes. The findings showed that male athletes were better than female athletes on all physical performance tests. They also concluded that in youth and adulthood, normative reference data show that men tend to have greater musculoskeletal strength than women, so the physical performance test results were expected. Women are more prone to falls during aging compared to men [45] due to a more significant decline in muscle mass and strength [46] and due to neuromuscular, biomechanical, and hormonal reasons [47], [48]. Therefore, the relationship between balance and lower-limb muscle strength is a significant risk predictor of falling [49]. The physiotherapy students did not differ according to gender.

We have confirmed our second and third hypotheses for the left limb, but not for the right limb. There is a correlation between the YBT test and the crossover hop test in the anterior ($p < 0.01$), posterior-medial, and posterior-lateral directions ($p < 0.05$) and the triple-hop test forward in the posterior-medial and posterior-lateral directions ($p < 0.05$) and anterior direction ($p < 0.01$) for the left extremity, except for an anterior direction to the right. With the right extremity, there is a correlation between the YBT test and the crossover hop test and triple-hop test forward in posterior-medial ($p < 0.05$), the crossover hop test in posterior-medial and posterior lateral to the left ($p < 0.05$) and right ($p < 0.01$), but no correlation in anterior direction in either of them. There is a correlation between performing YBT and sudden perturbation tests, but not in all directions or with both limbs. There is a correlation between YBT, AN, and TCHD in all directions with the left foot but none with the right foot. There is a correlation between YBT and THD, with the left foot to the left but not to the right. With the right limb, there is no correlation with either of the tests in the anterior direction.

The active body-weight shift test is a three-part test used to assess lower extremity balance and neuromuscular control [26]. Functional tests of the active body-weight shift test [2] require strength, mobility, neuromuscular control, stability, range of motion, balance, and proprioception and are related to lower limb strength. When performing the test, subjects must lean forward and backward to maintain balance, and the knee flexors must contract eccentrically to resist trunk movement [27], [50]. Poor results on the forward, backward, and inward reach tests can indicate chronic instability of the ankles [29].

The YBT test is helpful in determining ankle instability and the risk of an ankle sprain [30], as are the THD and TCHD tests. Ko *et al.* [30] tested patients with chronic ankle instability with four tests (THD, YBT, time-in-balance test, and foot lift test). They established that THD and YBT revealed the highest percentage of correctly matched values versus the control group and could capture functional performance. The tests are feasible with a commercially available dynamic balance measurement and assessment device [52].

Muscle activation changes across the various reach directions. In AN excursion, the m. vastus medialis is more active than in other directions. Even though our participants meet normative data, they seem not to be so stable in the sagittal plane, which can lead to less security when walking with patients and ensuring their stability. The ankle strategy is in healthy populations applied on stable surfaces, and the hip strategy is on unexpected postural perturbations. But nevertheless, we must consider center of pressure that controls the center of mass [53]. Since our participants did not have any injuries in their history, we can assume better results when standing on an undominant limb [54]. The differentiation is significant when differentiating dynamic stability [55]. Most of the studies showed no difference in postural balance [56], whereas other studies conclude that balance performance is not to be influenced by the leg dominance [57]. The influence of limb dominance can be context-dependent [56], which, on the other hand, should not be the case in providing patient safety in physical rehabilitation.

In the PL direction, the m. biceps femoris is significantly more active than in the AN direction. Activation of the m. tibialis anterior in PL and PM is considerably higher than in the AN direction [58]. Moreover, in a recent study, Kwon [59] confirmed the m. tibialis anterior activation while reaching in the AN direction. Garrison *et al.* [60] pointed out that YBT anteriorly is similar to the single-leg squat in that it requires a unilateral squat, and it is useful for measuring dynamic balance and monitoring recovery during rehabilitation, assessing athletes' readiness to return to sport after injury, identifying athletes at risk of injury [37], [54], [60] and reflecting the efficiency of intervention programs [10]. Lee *et al.* [24] have

confirmed the correlation between YBT and lower-limb strength in adult women, especially with hip extensors and knee flexors in the AN direction and hip extensors, hip adductors, and knee flexors in the PL direction. Several other studies have confirmed the activity of hip extensors [42], [61], [64], while greater hip range of motion is needed for the posterior direction [24], [65] and the activity of the hip abductor as a hip stabilizer [24]. There is also a correlation between YBT and knee flexors [24], [42], [66], [67]. In fact, when using only one dynamic test, the YBT appeared to be the best choice. Moreover, patients with patellofemoral pain syndrome show a reduction in dynamic postural control [68], [69] due to the quadriceps muscle activation [58]. A study [69] examined the correlation between isometric strength and performance in YBT or test jumps when performed after patellar stabilization surgery. They found no correlation between isometric strength and performance in YBT or test jumps. Thus, an extended rehabilitation program longer than 8 months was recommended to allow adequate recovery of muscle strength. Consequently, this would affect the return of strength and dynamic stability of the knee. Kim *et al.* [50] researched the criteria for participation in sports after ACL surgery. They found that knee-extensor strength deficits were significantly correlated with YBT. Kim *et al.* [51] concluded that YBT scores achieved by patients 1 year after ACL reconstruction showed no significant correlation with static balance. They have stated that after an injury to the anterior cruciate ligament, there is a lack of proprioception and transmission of information about joint movement. As a result, they have suggested that these factors reduce balance and, thus, functional capacity, which may increase the risk of musculoskeletal injuries.

Lee *et al.* [24] investigated the relationship between YBT distance and lower extremity strength in adult women. The research did not include sudden perturbation tests, but what they have found is not negligible, namely, that there is a weak correlation between lower extremity strength (hip extensors, hip abductors, and knee flexors) and dynamic postural control as measured by the YBT. We can conclude that muscle activation in our participants was good in the left limb but not in the right limb. Proper dynamic single-leg balance of physiotherapist is important for patients' safety and the prevention of falls of the patients in hospitals [62], [63], [70], [71], [72].

Strengths and limitations

As regards the strengths of our study, it should be noted that the research was done on a specific sample of young physiotherapy students of considerable size. The study also has some limitations. We did not check for the dominant leg or measure the muscle strength of

the lower limb. Furthermore, we did not measure the range of motion of the lower extremity. Further, research is needed to explore the impact of those factors.

Conclusion

The data of all physiotherapy students in our study meet the normative data, and no difference due to gender has been observed. There is a correlation between YBT, the dynamic balance test, and sudden disturbance tests with or without lateral movement on the left limb, but not on the right limb. We can assume better results when standing on an undominant limb, which can lead to insufficient support when standing on a dominant limb. That should not be the case in providing patient safety in physical rehabilitation.

Data Availability

The data are available on request from the corresponding author due to privacy and ethical restrictions.

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