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Effect of Balance Training Using Different Compliant Surfaces on Performance of One Leg Stance Test and Star Excursion Balance Test

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Abstract

In this study, the aim was to determine the effect of balance training using two different compliant surfaces (Sanddune® vs AirEx® balance pad) on performance of One Leg Stance Test (OLST) (eyes open and eyes closed) and Star Excursion Balance Test (SEBT) in healthy young adults. A repeated-measures design was used. Forty subjects participated in this study. Twenty participants were in each group (Sanddune® group and AirEx® group). Subjects performed the OLST to determine static balance and the SEBT to determine dynamic balance. One group of participants performed balance exercises on the AirEx® balance pad over a 6-week period of time twice per week, and the second group of participants performed balance exercises on the Sanddune® over a 6-week period of time twice per week. ANOVA (repeated measures and two ways) was used to analyse the data. The results showed that, The differences between the pre-test and post-test scores and the eyes-open and eyes-closed scores of the OLST were statistically significant, but there was no statistically significant interaction between variables. Statistically significant differences were also found between the pre-test and post-test scores with the right-leg and left-leg tests on the SEBT, and statistically significant interactions were also found between the pre-test and post-test and the three normal reaches. The results suggested that both devices significantly changed balance results on the OLST and the SEBT. These results will enable physical therapists to better advice and incorporate balance exercise protocols using compliant surfaces for their patients/clients to enhance balance.

Keywords: Balance; Balance exercises; One Leg Stance Test; Star Excursion Balance Test

Introduction

Performing daily activities requires good balance, whether one is at rest or in motion [1]. Controlling gravitational forces to maintain posture and controlling acceleration forces to maintain equilibrium are required for normal balance [2,3]. Studies have shown there are 130 risk factors that contribute to falls from losing balance [4,5]. The most common factors that lead to falls are impaired cognition, vision, mobility, weakness of lower limbs, slow reaction times, overall reduced muscle strength, poor balance, and decreased physical performance [4,6]. According to statistics, "muscle mass decreases by 50% between the ages of 20 and 90 years. This decrease results in strength loss, which has been associated with an increased risk of falling and osteoporosis [7]".

Nearly 30% of older community-dwelling adults fall once, and 10-20% fall twice or more annually [4,6]. Ninety percent of hip fractures in the Unites States are due to falls [4,8]. One in three adults aged 65 and older fall each year. Of those who fall, 20% to 30% suffer moderate to severe injuries that make it hard for them to get around or live independently and increase their risk of early death [9]. Older adults are hospitalized for fall-related injuries five times more often than they are for injuries from other causes. Twenty-seven percent of hospital costs are from falls, and the average hospital cost per person is $12,000 [4,10]. Worldwide, the older adult population has been increasing; therefore, post-fall complications are worse especially with fractures and lead to increased health-care costs [4]. "Currently, there is no 'gold standard' for measuring standing balance in an active young population, and accurate measurement of standing balance is essential in assessing the effectiveness of balance training [11]." The literature has shown that the achievement of both static and dynamic balance is based on coordination between the kinetic chain and the environment [12,13]. Evidence strongly suggests that physical activities improve balance and reduce the risk of falls in older adults. Thus, balance training is essential to prevent falls, decrease risk of injury, and enhance function post injury (4,8,14).

Lin and Woollacott compared postural muscle responses to changing balance threats in young adults and in stable and unstable older adults. They found that in both stable and unstable older adults, aging was accompanied by postural muscle activation changes in temporal and spatial organization. The changes were according to the level of balance ability and the size of postural threats. These changes potentially put older adults at high risk of loss of balance, and balance compensations are related to balance recovery. Thus, the balance training programs for older adults should be individualized, and clinicians should consider the functional stability level of the individual [15].

Tests and Measures of Balance

The main purpose of clinical balance assessments is to identify whether a balance problem exists and to determine the balance problem cause. It is important clinicians and researchers assess balance for early detection of people at high fall risk. The One-Leg Stance Test (OLST) evaluates performance, static posture, and balance control. It provides information on increased fall risk [16,17]. The Star Excursion

Balance Test (SEBT) is also an important tool for assessment and detection (12,16,18-21). It has the advantage over other dynamic balance tests in it poses challenges for healthy and athletic populations [22]. It is an objective measure of impairments and improvements in dynamic postural control with injuries to the lower limbs [18]. However, Kinzey and Armstrong found the SEBT was not a reliable measure for dynamic balance in everyone [23]. Overall, for those without trauma of the lower limbs, the OLST and SEBT are considered to be reliable in detecting postural balance responses to exercise. Therefore, these two tests were selected for this study [16,18,19,24,23,25].

Balance Training Programs

Balance training programs should be safe, challenging, incorporated multiple planes of motion and a multisensory approach, derived from fundamental movement skills that apply directly to an activity, followed a progressive integrated continuum, and included external resistance and a proprioceptive progression [12].

Ultimately, the following seven components are needed for effective balance training programs: body position, points of contact, head position, sight, visual input, surface, stance, and movement. Research suggests exercise can improve or maintain functional activities, and can increase muscle power, bone mineral density, and balance; thereby, reducing risk [6,26-35]. Balance training can efficiently enhance static postural sway and dynamic balance in both athletes and non-athletes. It is a beneficial treatment used in rehabilitation and prevention after injury or disease [36].

The research hypothesis was the Sanddune® is a valid balance pad for improving balance than the AirEx® balance pad, while the null hypothesis was that no differences would exist. To date no comparison studies have been found the effect of balance training on the Sanddune® vs AirEx® balance pad on performance of the OLST and SEBT. The aim of this study was to compare postural balance responses of healthy young adults on performance of the OLST and SEBT after balance training on these two different compliant surfaces. The training on both surfaces would enable physical therapists to select a surface for balance training that would facilitate appropriate exercise prescription.

Methods

Study Design

The study used a repeated-measures design.

Setting and Participants

Healthy adult individuals were included in the study if they met the following criteria: between 19 and 45 years; able to read and speak English (8th grade level); and had normal functional range of motion, normal functional muscle strength, and normal sensation in their upper and lower extremities. Participants were excluded if they: had any history or presence of debilitating musculoskeletal, neuromuscular, or cardiovascular/pulmonary diseases, disorders, or conditions; had any deficits in cognition, vision, hearing, or sensation; had any history of pain, surgery, or injury to the lower extremities in the previous six months; had consumed alcohol or drugs that might have altered their motor performance 24 hours prior to the study; had an abnormal waist circumference; had vestibular dysfunction; were unable to participate in the balance training program twice/week for 6 weeks; and were female volunteers who were pregnant. The subjects were recruited from New York University's Department of Physical Therapy and from the Saint Agnes Residence. Each participant gave informed consent. The University Committee on Activities Involving Human Subjects (IRB-FY2016-207) approved the study.

Materials

The OLST (eyes open and eyes closed) (Figure 1) is a simple test was used to evaluate static balance and fall risk after instructing the subject to stand on one leg for a specific period of time [16,12]. It is a valid measure [16,37] and reliable for health-related fitness with the eyes open [11,16,38]. "Inter-rater reliability is excellent with an intra-class correlation coefficient (ICC) of 0.994 (95% confidence interval (CI) 0.989-0.996) for eyes-open scores and 0.998 (95% confidence interval 0.996-0.999) for eyes-closed scores" [16,39]. It is a reliable test for evaluating the postural control efficacy under various sensory conditions.

Figure 1: One Leg Stance Test. Retrieved from: http://slccpta.weebly.com/balance.html.

This study used three of the eight reaching directions (anterior, posteromedial, and posterolateral) (Figure 2) to minimize redundancy in the original SEBT design [40-42]. "It is a highly reliable tool for measuring dynamic balance, and its intratester reliability is high. The ICC ranged from 0.82 to 0.99, the CI ranged from 0.65 to 0.99, and the method error (ME) ranged from 2.0 to 2.9. Additionally, the SEBT test-retest reliability ICC ranged from 0.89 to 0.91, ME ranged from 3.0 to 0.95 indicating good measurement stability, and its intertester reliability is high" (39,19,24). The AirEx® Balance Pad (Genairex Inc, 12501 71st Court Largo, FL-US) (Figure 3) is a compliant pad (20"L x 16.4"W x 2.5" thick) with a non-slip base to prevent it from sliding on the floor. The AirEx® pad has fair to good reliability, while the AirEx® foam had higher reliability scores with eyes closed [43].

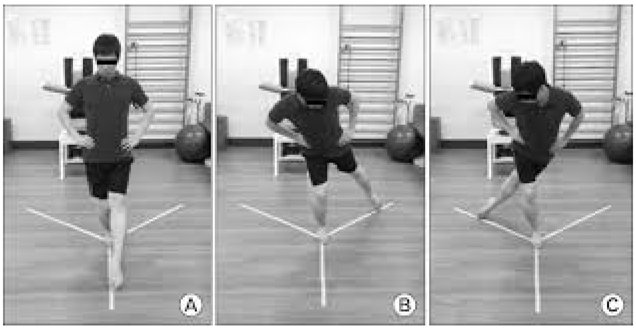

Figure 2: Star Excursion Balance Test directions and foot placement. Directions of the stance foot are: (A) anterior reach, (B) posteromedial reach, and (C) posterolateral reach. Retrieved from: https://www.oatext.com/the-effect-of-integrative-neuromuscular-training-on-postural-control-of-children-with-autism-spectrum.php#Figures_Data

Figure 3: The AirEx® balance pad. Retrieved from: https://www.carelinemedical.com/Balance-BoardsPads/Airexreg-balance-pad-Plus-16-x-20-x-25/

The Sanddune® (Sanddune Stepper, 81943 Ave Las Ramblas, Indio, CA 92203) (Figure 4) is a compliant low impact foam device that challenges balance and coordination of body movements. It is supportive, guiding, cushioning in nature, can be laid on any flat surface, and requires minimal set up. It mimics walking and exercising on the sand to promote greater balance, strength, coordination, and flexibility. The tape measure (Figure 5) was used to measure leg length and to quantify the reaching distance of the participant's leg while performing the SEBT. The tape measure is a valid and reliable instrument [44]. The Plastic universal goniometer (Figure 6) used to measure lower limbs range of motion. The goniometer has high intra-examiner reliability [45] and moderate inter-examiner reliability [46]. The stopwatch (Figure 7) was used for training and practice and was highly reliable (ICC=0.82) (see supplementary material).

Figure 4: The Sanddune®. Retrieved from: http://www.sanddunestepper.com/

Figure 5: The tape measure. Retrieved from: https://www.aliexpress.com/item/32838972138.html

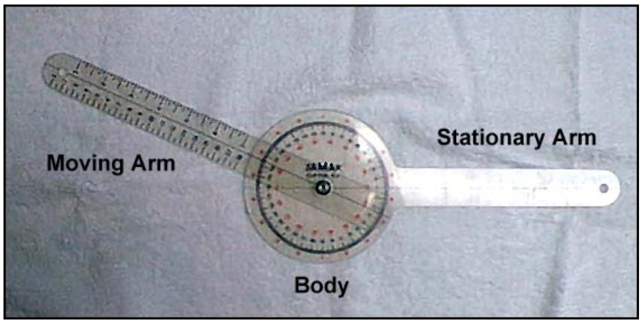

Figure 6: Plastic universal goniometer. Retrieved from: https://images.search.yahoo.com/yhs/search;_ylt=A0LEV7qz4QBaTQMA9hkPxQt.;_ylu=X3oDMTByMjB0aG5zBGNvbG8DYmYxBHBvcwMxBHZ0aWQDBHNlYwNzYw?p=michanical+morthon+stopwatch&fr=yhs-adk-adk_sbnt&hspart=adk&hsimp=yhs

Figure 7: Stopwatch. Retrieved from: https://images.search.yahoo.com/yhs/search;_ylt=A0LEV7qz4QBaTQMA9hkPxQt.;_ylu=X3oDMTByMjB0aG5zBGNvbG8DYmYxBHBvcwMxBHZ0aWQDBHNlYwNzYw--?p=michanical+morthon+stopwatch&fr=yhs-adk-adk_sbnt&hspart=adk&hsimp=yhs-adk_sbnt#id=27&iurl=http%3A%2F%2Fwww.onetigris.com%2Fwp-

Procedures

Participants were identified as meeting all of the inclusion criteria and not having any of the exclusion criteria of the study through a pre-participation questionnaire. Participants had their range of motion, strength, and sensation of both lower and upper extremities tested to assure that all parameters were normal. Data were collected during two sessions lasted approximately 45 minutes for the initial assessment, and 10-15 minutes for the reassessment session. The examiner collected data using the standardized procedures for the performance of the OLST for static balance and SEBT for dynamic balance. The participant's age, height, and weight were recorded. In addition, leg length, foot length, waist circumference, and the lower limb range of motion were measured. For screening purposes, the Back-Scratch Test was used to determine upper extremity range of motion. All participants squeezed the investigator's hands as firmly as possible to determine grip strength indicating upper extremity strength. They performed a full squat to determine lower extremity functional range of motion and strength, and their sensation was determined by stroking the skin of the upper and lower extremities with a cotton swab. The balance pad was selected randomly for the participant by coin toss. Each side of the coin represents a balance pad. The protocol was begun with a warm-up of 30 seconds and baseline balance was assessed by using the OLST for static balance and the SEBT for dynamic balance. The OLST was assessed with eyes open, while the subject was standing bare footed and with the arms folded across the chest (pg. 6). When the commands "ready and go" were given, the middle button on the stopwatch was pressed and at the same time the subject began to raise the non-dominant leg off the floor. The subject was instructed to stop at the end of the 30 seconds, while the second button on the stopwatch was pressed simultaneously. The participant did the same thing on the non-dominant leg [16], and was terminated if the subject moved the weight bearing foot, if the suspended foot touched the ground, if the subject used the suspended limb to support the weight-bearing limb, or if the arms came unfolded. The procedure was repeated with eyes closed. A thirty-second rest period was given between tests [21]. This test was performed only once on each leg because our interpretation of the previous studies was highly valid and reliable (test-retest) (47,38,48,11,37,39,16). The SEBT was assessed by starting with the dominant leg in the centre of the grid bare footed and reaching with other leg in three reaching directions (anterior, posteromedial, and posterolateral) (pg. 6). The subject reached the farthest possible point with the tip of the big toe with the hands on the hips. The participant returned to the starting position after each reach while maintaining balance. The subject was not to move the supporting foot from the centre. The test was repeated if the subject failed to maintain the correct stance, if the stance foot moved from the grid, or if the subject failed to return to the starting point. The subject performed three reaches in each of the test directions and rested for thirty seconds at the end of the test. Then, the participant performed the test reversing the leg positions [18-21,23-25]. Since the OLST and SEBT instructions were easy to follow and administer, subjects found no difficulty understanding the instructions of either test.

Balance Exercises

One group of participants performed balance exercises on the AirEx® balance pad (pg 6) while a second group of participants performed balance exercises on the Sanddune® (pg 6). These exercises were done twice per week over 6 consecutive weeks (see supporting information).

Results

The pre-test and post-test measures for the OLST and SEBT for both groups were used for data analysis. The data were analysed using the SPSS software (version 23.0). ANOVA (repeated measures and 2 ways) was used to compare the mean differences between groups to determine if an interaction was found between the two independent variables on the dependent variables. The alpha level was set at 0.05 for significance and 95% confidence intervals (CIs). Results of the ANOVA of the OLST and SEBT were expressed as mean differences through an analysis of dependent-variables variance explained by the two grouping variables and the interaction between the two grouping variables. The average age of the Sanddune® participants (n=20) was 27.65 +/- 5.15 years and of the AirEx® participants (n=20) was 29.55 +/- 6.65 years (Table 1). All forty subjects completed the balance program twice per week either on the Sanddune® or on the AirEx® balance pad.

According to the OLST results, two main effects-(1) pre-test vs. post-test and (2) eyes-open vs. eyes-closed-were found to be statistically significant. For the pre-test and post-test measures, the difference in the mean was 2.601 [p=0.002] with a 95% CI of (0.984, 4.217) (Table 2).

Variables	SG n=(20) Mean ± (SD)	95% confidence interval		AG n=(20) Mean ± (SD)	95% confidence interval		Sig.
		Lower	Upper		Lower	Upper	
Age (y)	27.65 (5.15)	25.7	29.5	29.55 (6.65)	22.45	28.66	.000

Weight (lb)	143.42 (25.20)	133.14	149.59	141.32 (26.82)	124.76	149.87	.000
Height (cm)	168.57 (9.27)	164.39	169.68	167.50 (7.36)	160.06	166.94	.000
Gender	1.75 (.44)	0.61	0.89	1.75 (.44)	-2.46	-2.04	.000
Note: SG; Sanddune group; AG; AirEx group; y=years; lb=pounds; cm=centimetres; Sig=significance; α=0.05							

Table 1: Anthropometric data of all participants (N=40).

(I) pre-post	(J) pre-post	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-2.601*	.798	.002	-4.217	-.984
2	1	2.601*	.798	.002	.984	4.217
Based on estimated marginal means						
*.The mean difference is significant at the .05 level.						
a=Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).						

Table 2: Pre-and post-pairwise comparisons of the OLST.

For the eyes-open and eyes-closed measures, the difference in the balance measures between the eyes-open and the eyes-closed measurements in the mean was 12.230 [p=0.000]. This difference was within a 95% CI between 9.956 and 14.504 (Table 3). No statistically significant interaction was found [F (1,38)=0.522, P=0.47] (Table 4).

According to the SEBT results, two main effects-(1) pre-test vs. post-test and (2) right leg vs. left leg-were found to be statistically significant. For the pre-test and post-test measures, the difference in the mean was 6.296 [p=0.000] with a 95% CI of (4.232, 8.360) (Table 5).

(I) open closed	(J) open closed	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	12.230*	1.123	.000	9.956	14.504
2	1	-12.230*	1.123	.000	-14.504	-9.956
Based on estimated marginal means						
*.The mean difference is significant at the .05 level.						
a=Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).						

Table 3: Eyes open and closed pairwise comparisons of the OLST.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	86168.751	1	86168.75	1294.561	.000	.971
Device	34.759	1	34.759	.522	.474	.014
Error	2529.361	38	66.562			
Transformed Variable: Average						

Table 4: Tests of between-subjects' effects of the OLST.

(I) pre-post	(J) pre-post	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound

1	2	-6.296*	1.020	.000	-8.360	-4.232
2	1	6.296*	1.020	.000	4.232	8.360
Based on estimated marginal means						
*.The mean difference is significant at the .05 level.						
a=Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).						

Table 5: Pre-and post-tests pairwise comparisons of the SEBT.

For the right leg and left leg measures, the difference in the mean was 1.329 [p=0.041] with the right leg measure on the whole performing better than the left leg measure. This difference was within a 95% CI between 0.060 and 2.598 (Table 6). Two interactions (Table 7)-(1) pre-test and post-test measures vs. the three normal reaches [p=0.006] (Figure 8) and (Figure 2) right leg and left leg measures vs. the three normal reaches [p=0.003] (Figure 9)-were found to be statistically significant.

(I) right left	(J) right left	Mean Difference (I-J)	Std. Error	Sig.a	95% Confidence Interval for Differencea	
					Lower Bound	Upper Bound
1	2	1.329*	.627	.041	.060	2.598
2	1	-1.329*	.627	.041	-2.598	-.060
Based on estimated marginal means						
*.The mean difference is significant at the .05 level.						
a=Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).						

Table 6: Right and left leg pairwise comparisons of the SEBT.

		Value	F	Hypothesis df	Error df	Sig.
pre_post	Pillai's Trace	.501	38.120b	1.000	38.000	.000
	Wilks' Lambda	.499	38.120b	1.000	38.000	.000
	Hotelling's Trace	1.003	38.120b	1.000	38.000	.000
	Roy's Largest Root	1.003	38.120b	1.000	38.000	.000
right_left	Pillai's Trace	.106	4.496b	1.000	38.000	.041
	Wilks' Lambda	.894	4.496b	1.000	38.000	.041
	Hotelling's Trace	.118	4.496b	1.000	38.000	.041
	Roy's Largest Root	.118	4.496b	1.000	38.000	.041
pre_post* NormReach_a_p_m	Pillai's Trace	.243	5.947b	2.000	37.000	.006
	Wilks' Lambda	.757	5.947b	2.000	37.000	.006
	Hotelling's Trace	.321	5.947b	2.000	37.000	.006
	Roy's Largest Root	.321	5.947b	2.000	37.000	.006
right_left* NormReach_a_p_m	Pillai's Trace	.265	6.680b	2.000	37.000	.003
	Wilks' Lambda	.735	6.680b	2.000	37.000	.003
	Hotelling's Trace	.361	6.680b	2.000	37.000	.003
	Roy's Largest Root	.361	6.680b	2.000	37.000	.003

a. Design: Intercept+Device
Within Subjects Design: pre_post+right_left+NormReach_a_p_m+pre_post* right_left+pre_post* NormReach_a_p_m+right_left* NormReach_a_p_m+pre_post* right_left* NormReach_a_p_m
b=Exact statistic

Table 7: Multivariate tests[a] of the SEBT.

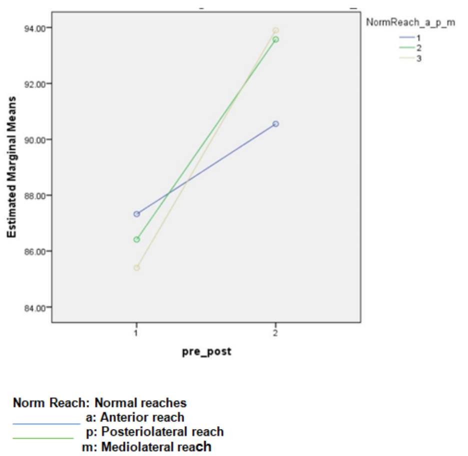

Figure 8: The interaction between pre vs. post measures and normal reach anteriorly, posterolaterally, and mediolaterally on the SEBT.

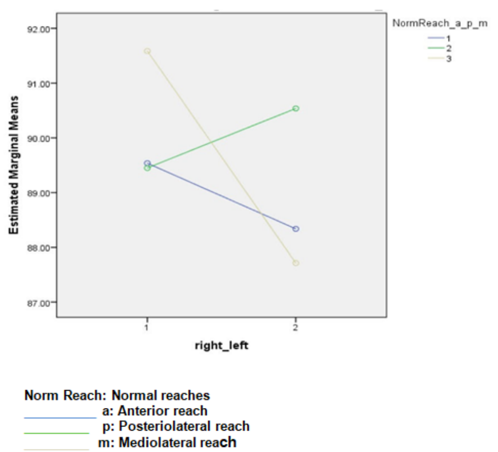

Figure 9: The interaction between right leg vs. left leg measures and normal reach anteriorly, posterolaterally, and posteriomedially on the SEBT.

Discussion

The purpose of this study was to compare postural balance responses of healthy young adults on performance of the OLST and SEBT after balance training on these two different compliant surfaces. Our results revealed that a statistical significant of two main effects were found for each test: the OLST-was between pre-test vs. post-test and eyes-open vs. eyes-closed; and the SEBT-was between pre-test vs. post-test and eyes-open vs. eyes-closed, and two interactions were found between pre-test and post-test measures vs. the three normal reaches and right leg and left leg measures vs. the three normal reaches. The research Hypothesis was not confirmed based on comparison of the pre-test and post-test measures for both groups, the balance systems can be challenged, and the balance of a patient/client can be trained without considering the type of compliant surface. While limited knowledge exists on the effect of training with both (Sanddune® and AirEx® balance pad) compliant surfaces, no significant difference was found in the mean difference of the OLST and SEBT performance after training with either compliant surface. Previously, balance-training programs using a wobble board [47] and a Biomechanical Ankle Platform System have shown balance improvement [49]. Riemann et al. concluded that during balance on firm foam and multiaxial surfaces, the ankle joint was very important. They observed the contributions of the ankle, knee, hip, and trunk to corrective actions during eyes open and eyes closed conditions and various surfaces and noted the proximal joints had a greater role under more challenging conditions [50]. The findings of this current study were consistent with Holm et al and Paterno et al, who reported balance could be improved after 6 to 7 weeks of a balance-training program [11,51-53], while researchers demonstrated balance could improve in a shorter time for young healthy adults [54].

In contrast to this study, researchers found that the "AirEx® and Neurocom foam pads both provide fair to good reliability and the AirEx® pad had higher reliability scores with eyes closed than Neurocom pad [3,11]. [14] Concluded that a significant difference existed between the Both Sides up (BOSU) trainer and three other devices (AirEx® balance pad, half-foam, and DynaDisc) for the level of difficulty (COP area and sway velocity) during balance training, which would assist physical therapists in progressing balance-training programs for patients [14]. [55] Revealed that there was a large significant difference in losing balance on the mung bean bag and plastic bead bag than on a foam pad in healthy young adults, but there was no significant difference in losing balance between the mung bean bag and the plastic bead bag. Those bags had been suggested for balance assessment instead of a foam pad for the same group of people. Interestingly, in the present study, we found that balance improved after 6 weeks. However, there was no correlation between balance improvement and type of balance device. New hypotheses that were emerged to the surface post conducting this paper; first, is there a relationship between impaired on the SEBT performance and injury prediction? Second, is there a relationship between impaired on the SEBT performance and a dominant leg? Finally, is the OLST a useful test for examining dynamic balance especially when conjunction with dynamic tests? Study's limitations were a small sample size, a short duration, and a difficult commitment for twice per week for six weeks.

Conclusion

This study concluded that balance performance measures for the OLST and SEBT were significantly increased with a 6-week balance-training program on compliant surfaces (Sanddune® and AirEx® balance pad). Training on either type of compliant surface resulted in the same outcomes thus providing knowledge for balance training or rehabilitation programs. Also, the results showed that both devices significantly changed balance results on the OLST and the SEBT. These results will enable physical therapists to better advice and incorporate balance exercise protocols using compliant surfaces for their patients/ clients to enhance balance. We suggested that replication of this study with a larger sample size, and with a sample composed of individuals with balance and vestibular dysfunction might prove useful. Future research might investigate other types of balance equipment, and investigate whether the SEBT reach distances improve after completing neuromuscular training programs.

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