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Test-retest reliability of postural sway on foam and natural rubber pads in healthy adults

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Abstract

Introduction. Postural control is essential for humans to maintain balance under both static and dynamic conditions. A variety of unstable support surfaces are used to evaluate postural control. Balance foam pads are relatively expensive, whereas natural rubber pads use a natural material with equivalent viscoelastic properties that are inexpensive and widely available. No postural sway and reliable data existed to support the practice of using a natural rubber pad. The purposes of the study were to determine the test-retest reliability of postural sway by using a natural rubber pad and to compare postural sway in healthy adults while using a foam pad, a natural rubber pad and a firm surface.

Methods. Nineteen healthy participants were measured for centre of pressure (COP) velocity and displacement during a quiet stance, with their eyes closed, on a balance foam pad (blue foam – Airex®), a natural rubber pad and a firm surface on a force platform. Two repeated sessions were conducted three days apart. Intraclass correlation coefficients were used to determine the test-retest reliability. A one-way repeated measures ANOVA was used to compare the three surface conditions.

Results. The natural rubber pad demonstrated moderate to good reliability for COP velocity and COP displacement. Also, there were no significant differences in anteroposterior (AP) and mediolateral (ML) COP velocity and displacement between the balance foam pad and the natural rubber pad.

Conclusions. Our findings indicate that a natural rubber pad could be employed as a low-cost alternative to the balance foam pad for evaluating the balance of healthy adults.

Key words: postural sway, reliability, natural rubber pad

Introduction

Balance, also known as postural control, is an important ability for performing daily activity tasks, such as standing, walking and running. Coordination between the vestibular, visual, and proprioceptive senses is considered necessary for postural control [1]. Postural control is defined as compressing the body sway caused by external perturbation to maintain the centre of gravity (COG) within the base of support (BOS) [2]. There are numerous contributing factors that impact balance control, so testing the balance during a quiet stance is a good indicator of human health. However, in some cases, it is not a strong indicator of underlying disorders [3]. This is because balance is the result of a complex interaction between individual, environmental, and task factors [4]. Nevertheless, balancing with a quiet stance on an unstable support is a suitable method for increasing the difficulty of a balancing task [5]. A balance foam pad is commonly used to challenge postural control [6] because it has a high perturbation due to its compliant viscoelastic surface, which influences proprioceptive and mechanoreceptive inputs into the central nervous system (CNS). In addition, the balance foam pad demonstrates fair to good reliability in terms of sway path length [5].

To the best of our knowledge, most physical therapists use an unstable support surface for clinical use in both testing and training. There are several clinical tests that require foam pads to assess the postural control, such as the Biodex Balance System (BBS), the Clinical Test of Sensory Interaction and Balance (CTSIB), the modified CTSIB (mCTSIB) [7], the modified Romberg test using a foam pad (MRuFP) [8], and the Balance Error Scoring System (BESS). The BESS is commonly used by physical therapists and researchers to test static balance [9]. This test was developed as an outcome measure of postural control. The BESS test consists of three positions with two different types of support surfaces (on a firm surface or a foam surface), which allow examiners to discriminate between healthy individuals and those with balance disorders [5]. The BESS can detect balance deficits in individuals who are concussed and fatigued, and BESS scores increase with ankle instability and age [9]. Likewise, in the modified CTSIB, this test consists of two different types of support surfaces, performed with eyes open or closed under four balance conditions. The mCTSIB is also frequently used in clinical practices due to its simplicity [10].

Previous studies have demonstrated the effects of balance pads on standing postural control [3, 9, 11, 12]. There are also numerous types of unstable support surfaces for assessing postural control. Several studies indicated that material properties influence postural control, such as thickness, indentation force and Young's modulus [3, 13]. While, MacLellan et al. [14] revealed that the mechanical properties of the compliant surface also affect postural control. The balance foam pad is a useful and important tool for most physical therapists in both prehabilitation and rehabilitation processes. However, higher-quality products are typically more costly. The balance foam pad is relatively expensive and, in some cases, difficult to purchase, whereas natural rubber is a natural material that has similar viscoelastic properties and durability but is inexpensive and easily available.

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A comparison of a natural rubber pad (our sample) with a standard-balance foam pad (blue foam – Airex®) in the assessment of postural control would provide us with relevant information on postural sway. So, our goal for this study was to create a low-cost natural rubber pad that could be used to measure postural control in healthy adults. As there were no reliable data on postural sway to support the use of our natural rubber pad, the aims of the study were: (1) to determine the test-retest reliability of postural sway while using the natural rubber pad; and (2) to compare the postural sway of healthy adults by using a balance foam pad, a natural rubber pad and a firm surface. We assumed that the postural sway (COP velocity and COP displacement) of healthy adults during a quiet stance, with their eyes closed, on a natural rubber pad would be similar to performing the same stance on a standard-balance foam pad (the null hypothesis).

Subjects and methods

Natural pad preparation and material properties

The natural rubber pads were prepared using the Dunlop process. Natural rubber latex was mixed with potassium oleate, sulphur, zinc-diethyldithiocarbamate (ZDEC), zinc 2-mercaptobenzothiazole (ZMBT) and a phenolic-type antioxidant (Lowinox® CPL) using a mechanical stirrer (IKA® RW20) at 50 revolutions per minute (rpm) for 10 minutes. The mixture was thoroughly beaten using a mixer (V-KEEPER®) at a speed of 300 rpm until the initial volume was doubled (2 min). After that, zinc oxide and diphenyl guanidine (DPG) were added as the secondary gelling agent and mixed at a speed of 85 rpm. Sodium silicofluoride (SSF), the primary gelling agent, was added, and the mixture was homogenised for an additional 30 s. The foam was then immediately poured into aluminium moulds and allowed to gel at room temperature for five minutes. The gelled foams were then vulcanised in a hot steam oven for one hour to form the rubber pads. After the rubber pads had been vulcanised, they were taken from the mould and carefully cleaned with water to eliminate any unreacted substances. The rubber pads were washed and dried in a 70°C hot air oven for 24 hours. Table 1 provides the formulation details for the rubber pads.

A universal testing machine (INSTRON Corp, USA) was used to apply compression force to the balance foam and natural rubber pads (Condition: Load cell – 5 kN, compression speed – 100 mm/min) to assess the reduction in thickness at 25% and 40% of full thickness.

Table 1. Formulation of the rubber pads

Chemical	Concentration (% w/w)	Quantity (phr)
NR latex	60	100
Potassium oleate solution	20	1.5
Dispersion of ZDEC	50	1
Dispersion of ZMBT	50	1
Dispersion of sulphur	60	2
Dispersion of Lowinox® CPL	50	1
Dispersion of zinc oxide	50	5
Dispersion of DPG	30	1
Dispersion of SSF	23	1

phr – parts per hundred rubber, % w/w – percent by weight

Participants

Nineteen healthy adults volunteered to participate in this study. The characteristics of the participants are shown in Table 2. The inclusion criteria were that the participants: (1) must be able to stand unaided with their eyes closed for 90 s, (2) had no known visual defects, (3) had no history of musculoskeletal or neurological disorders, (4) had no history of back or lower limb surgery, (5) had normal muscle strength and power in the lower limbs that was also evaluated by manual muscle testing (MMT), and (6) had not consumed alcohol within 48 hours prior to the test.

The exclusion criteria included participants with: (1) lower limb musculoskeletal pathologies that may have impaired their ability to stand unaided, and (2) rubber or latex allergies. Participants were informed about the experiment protocols and gave their informed consent, signed by their own self-determination.

Table 2. Characteristics of participants (n = 19) (mean ± SD)

Characteristics	
Sex	9 males and 10 females
Age (years)	32.6 ± 10.5
Weight (kg)	57.8 ± 8.7
Height (m)	1.6 ± 0.1
BMI (kg/m^2)	20.9 ± 1.6

Postural sway

All participants were assigned to either a firm pad (faceplate), balance foam pad (blue foam – Airex®), or natural rubber pad conditions in a counterbalanced order. The participants were requested to warm up 10 min before the test by walking at the preferred speed for 30 m. In each trial, the participants were instructed to stand barefoot with their feet together while standing as still as possible with their eyes open for 30 s and then eyes closed for 30 s. They used controlled foot positions for each trial using even distances between both big toes (hallux) and the centre of the heels. Three trials were tested for each condition, separated by a 5-minute resting period. A successful trial was recorded when the subject maintained the testing stance for the entire 30-second trial. Two repeated sessions were separated by three days. The sway velocity and sway displacement were measured using a force platform (Kistler Instrument Corp, USA).

Data analysis

Kinetic data was collected at the sampling rate of 200 Hz and filtered through a 10th order low-pass Butterworth filter at a cut-off frequency of 7 Hz [15]. All results are presented as mean ± standard deviation (SD). The normality of data was measured with the Shapiro–Wilk test. The mean data from the two sessions were compared on the sway velocity and sway displacement data for the three conditions, using a one-way repeated measure ANOVA. This was followed by a Bonferroni post-hoc analysis to determine the differences between each surface. Multiple comparisons were calculated for surface conditions. The Bonferroni adjustment determined significant differences for surface groups (firm pad vs. Airex® vs. natural rubber pad). Dependent variables were statistically significant with a p-value < 0.01 (0.05/3). Intraclass correlation coefficients [ICC (3,1)] were used to determine the test-retest reliability between the days. The ICC for reliability is defined as excellent if it was above 0.90; good if it was between 0.75 and 0.9; moderate between 0.50 to 0.74; and poor for values less than 0.5 [16]. The level of significance was set at $p < 0.05$. The standard error of measurement (SEM) was calculated using the formula $SEM = SD \times \sqrt{(1\text{-}ICC)}$, where SD is the standard deviation of all data and ICC is the intraclass correlation coefficient. The confidence level was set at 95% and the minimum detectable change (MDC) indicator was calculated from the formula MDC = 1.96 × *SEM* [17, 18]. A Bland-Altman plot graph was used to calculate the agreement between two different pads [19].

Results

The maximum load at 25% and 40% of its original thickness between the balance foam and natural rubber pads are shown in Table 3. The balance foam has a higher force than the natural rubber pads (746.07 ± 12.00 N vs 592.73 ± 9.70 N and 1661.67 ± 9.07 N vs 1113.20 ± 24.68 N), whereas the natural rubber pads had a density of 0.178 g/cm^3, while the balance foam was 0.061 g/cm^3. The physical properties of the balance foam and the natural rubber pad are shown in Table 3.

The sway velocity and sway displacement of the balance foam and natural rubber pad were significantly different compared with the firm surface ($p = 0.00$). However, no significant differences were observed between the balance foam and natural rubber pad ($p > 0.05$). The sway velocity and sway displacement data between the balance foam, natural pad and firm surface conditions are shown in Table 4.

The natural rubber pad showed poor to good reliability [ICC (3,1) = 0.30–0.89, $p = 0.004$] for AP displacement and moderate to excellent reliability for AP velocity [ICC (3,1) = 0.68–0.97, $p = 0.000$], whereas ML velocity and displacement had moderate to excellent reliability [ICC (3,1) = 0.70–0.96, 0.62–0.94, $p = 0.000$, 0.000], respectively. Similarly, the balance foam pad showed poor to good reliability [ICC (3,1) = 0.19–0.87, $p = 0.009$] for AP displacement and poor to excellent reliability for ML displacement [ICC (3,1) = 0.49–0.92, $p = 0.001$]. Meanwhile, the AP velocity showed good to excellent reliability [ICC (3,1) = 0.82–0.98, $p = 0.000$] and moderate to excellent for ML velocity [ICC (3,1) = 0.61–0.95, $p = 0.000$]. The natural rubber pad had higher SEM values than the balance foam pad for all variables except ML displacement. The minimum detectable change (MDC) for all variables is shown in Table 5.

For the descriptive agreement analysis between the natural rubber and balance foam pads, we used the Bland-Altman plot graph for the mean difference and a limit of agreement of 95% CI. For AP displacement, the mean difference between the natural rubber and balance foam pads was 3.43 with limits of agreement between 16.33 and –9.45 (Figure 1). The mean difference for ML displacement between the natural rubber

Table 3. Physical properties of different types of balance foam and natural rubber pads

	Balance foam – Airex®	Natural rubber pad
Dimension (cm): width × length	41 × 50	40 × 40
Thickness (cm)	6.0	5.3
Density (g/cm^3)	0.061	0.178
25% thickness reduction (N)	746.07 ± 12.00	592.73 ± 9.70
40% thickness reduction (N)	1661.67 ± 9.07	1113.20 ± 24.68

Table 4. Sway velocity and sway displacement data between the balance foam, natural rubber pad and firm surface conditions

Variables	Balance foam – Airex®		Natural rubber pad		Firm surface		*p*-value	Effect size
	mean ± *SD*	95% CI	mean ± *SD*	95% CI	mean ± *SD*	95% CI		
AP velocity (mm/s)	18.80 ± 0.94*	16.81–20.80	19.70 ± 1.33*	16.90–22.50	6.13 ± 0.31	5.48–6.79	< 0.01	0.88
AP displacement (mm)	45.87 ± 5.62*	43.16–48.58	42.19 ± 6.20*	39.20–45.18	16.58 ± 4.60	14.63–18.54	< 0.01	0.94
ML velocity (mm/s)	12.24 ± 0.64*	10.88–13.59	12.39 ± 0.81*	10.69–14.09	4.46 ± 0.28	3.87–5.05	< 0.01	0.87
ML displacement (mm)	34.28 ± 1.85*	30.39–38.17	32.95 ± 1.91*	28.93–36.96	9.01 ± 0.71	7.50–10.51	< 0.01	0.90

AP – anteroposterior, ML – mediolateral
* significant difference from firm surface ($p < 0.01$)

Table 5. Test-retest between-day reliability (intraclass correlation coefficient with two-way mixed model)

Variables	Balance foam – Airex®			Natural rubber pad			Firm surface		
	ICC (95% CI)	SEM	MDC	ICC (95% CI)	SEM	MDC	ICC (95% CI)	SEM	MDC
AP velocity	0.94 (0.82–0.98)*	1.06	2.93	0.90 (0.68–0.97)*	1.89	5.24	0.83 (0.51–0.94)*	0.58	1.62
AP displacement	0.68 (0.19–0.87)*	3.62	10.02	0.72 (0.30–0.89)*	3.68	10.20	0.73 (0.32–0.89)*	2.37	6.56
ML velocity	0.86 (0.61–0.95)*	1.33	3.69	0.89 (0.70–0.96)*	1.45	3.69	0.87 (0.64–0.95)*	0.34	0.95
ML displacement	0.80 (0.49–0.92)*	3.27	9.05	0.85 (0.62–0.94)*	2.93	8.11	0.93 (0.82–0.97)*	1.15	3.20

SEM – standard error of measurement, MDC – minimum detectable change, AP – anteroposterior, ML – mediolateral
* significance value at $p < 0.01$

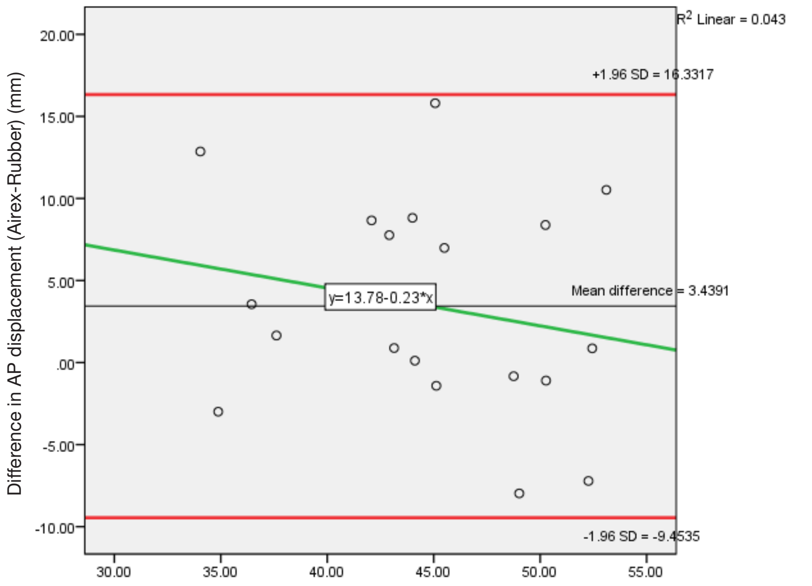

Figure 1. Bland-Altman plot graph showing the mean difference AP displacement (mm) between natural rubber and balance foam pads

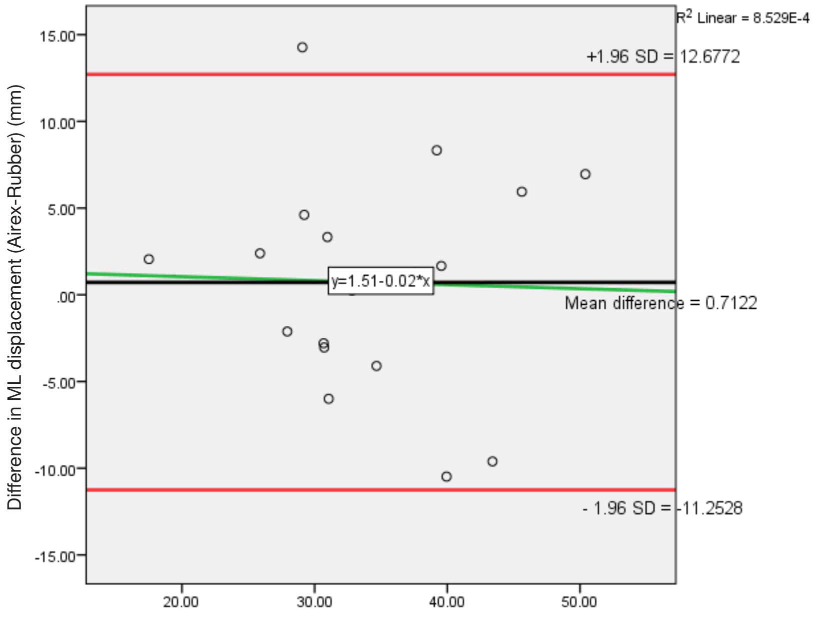

Figure 2. Bland-Altman plot graph showing the mean difference ML displacement (mm) between natural rubber and balance foam pads

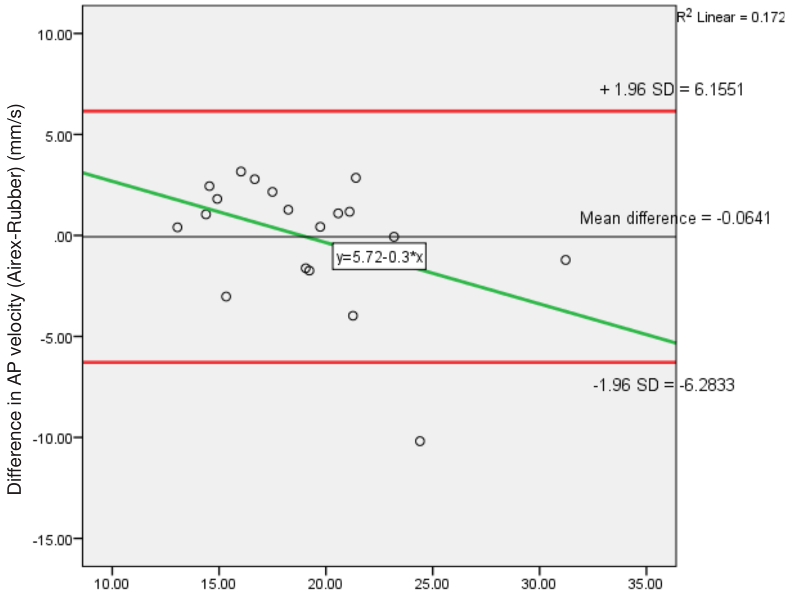

Figure 3. Bland-Altman plot graph showing the mean difference AP velocity (mm/s) between natural rubber and balance foam pads

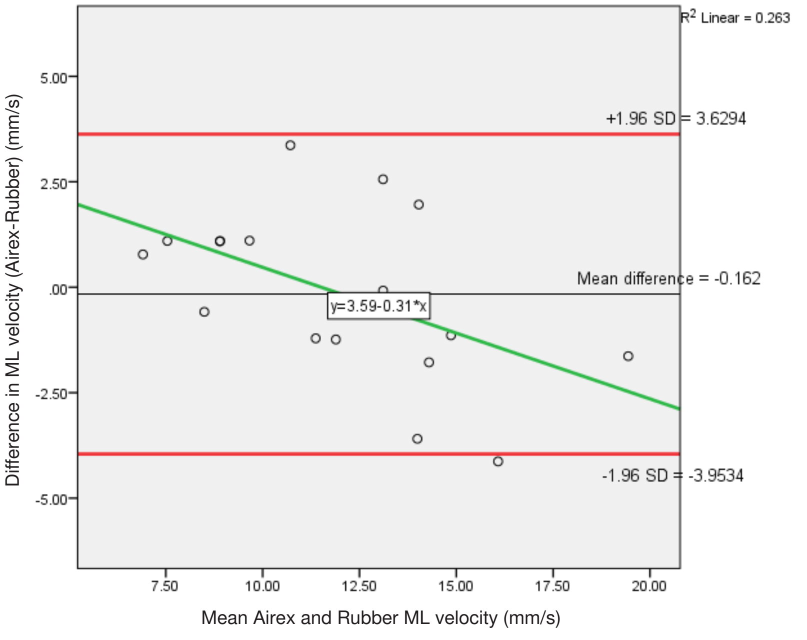

Figure 4. Bland-Altman plot graph showing the mean difference ML velocity (mm/s) between natural rubber and balance foam pads

and balance foam pads was 0.71 with limits of agreement between 12.68 and –11.25 (Figure 2). For AP velocity, the mean difference was –0.06 with limits of agreement between 6.16 and –6.28 (Figure 3). The mean difference of ML velocity between the natural rubber and balance foam pads was –0.16 with limits of agreement between 3.93 and –3.95. Of the total measurements conducted between the pads, 5% (1/19) did not fall within the limits of agreement, except AP displacement (Figure 2).

Discussion

The primary objective of this study was to determine the test-retest reliability of postural sway by using a natural rubber pad, and the secondary objective was to compare the postural sway of healthy adults while using a balance foam pad, a natural rubber pad, and a firm surface.

This is the first study to investigate the efficacy of a natural rubber pad in increasing the distribution of postural sway in healthy adults. We compared postural sway (COP velocity and COP displacement) between balance foam and natural rubber pads, and the main findings revealed that both pads increased postural sway when compared to a firm surface. According to previous literature, the somatosensory information from cutaneous mechanoreceptors is reduced while standing on a balance pad, which exacerbates balance deficits [20]. This is because postural control needs consistent information from the vestibular, visual, and somatosensory inputs, and when these inputs are interrupted, the ability to control balance declines [4, 21].

The centre of pressure (COP) is the point at which the ground's vertical reaction forces act. It indicates the weighted average of all pressures over the body in contact with the ground [3]. Continuous, small corrective movements, known as postural sway, usually occur during a quiet stance [6], which is often assessed by measuring the COP [3]. However, until recently, the optimal parameter for COP was not well documented [22]. As such, for this study, we decided to measure COP velocity and displacement in the assessment of postural stability to represent the postural sway during a quiet stance. In addition, various factors have been associated with an increase in the average centre of pressure change, including ageing, obesity, neuropathy, Parkinson's disease, vestibular loss, stroke (individual factors), and other factors, such as environmental and task-specific postural demands [4, 23–26]. Therefore, disruption to somatosensory input from injury, disease, or health conditions can also lead to both local and central deficits in motor performance related to balance and proprioception [21]. In line with these identified mechanisms, the healthy adult subjects in this study exhibited significantly greater sway velocity and displacement from the balance foam and natural rubber pads than a firm surface. Consequently, the results obtained from the COP measurements indicated that there was no statistically significant difference between the balance foam and natural rubber pads.

Natural rubber exhibits a comparable indentation force to balance foam. It is a unique material that is both elastic and viscous and responds to compression load and possesses properties such as shock absorption, vibration and deformation. This is contrary to a previous study by Lee et al. [27], who reported that a Dynair Ballkissen pad increased postural sway compared to a balance foam pad because it was filled with air and was not as firm. Likewise, Siriphorn et al. [2] examined postural stability while standing on mung bean and plastic bead bags and found that both bags had a greater impact on postural sway than a foam pad. The nodule forms of mung beans and plastic beads disturbed the somatosensory system via the cutaneous receptors. In line with the previous study, Gosselin and Fagan [3] found that during a quiet stance, the foam pad with the highest modulus of elasticity would exhibit the greatest change in postural sway velocity. Consequently, foam pads with different densities and Young's moduli produced various balance test results [6, 7]. Foam with the proper density (optimal thickness) complied with the body weight and triggered body sway in the appropriate proportion [6, 13]. Patel et al. [6] then suggested that the foam's properties may influence the body movements when evaluating balance deficits with a foam pad. Thus, the observation of comparable postural sway between the balance foam and natural rubber pads may be attributable to the similar properties of these two materials, which affect postural sway in a similar manner during a quiet stance.

In terms of test-retest reliability, the natural rubber pad demonstrated moderate to good reliability for sway velocity and sway displacement, which is comparable to the balance foam pad. For SEM values, the natural rubber pad was as consistent as the balance foam pad. Similarly, the natural rubber pad has MDC values that detect the changes in COP velocity and displacement similar to the balance foam pad. Likewise, Lin et al. [5] observed that the balance foam pad exhibited fair to good reliability for sway path length. The descriptive agreement analysis between the natural rubber and the balance foam pads was done using a Bland-Altman plot with a mean difference and limit of agreement of 95% CI. We found that both pads were in agreement with each other because the points on the Bland-Altman plot were scattered all over, both above and below the zero line (mean difference) [28]. However, we acknowledge that our natural rubber pad may overestimate the value of the AP displacement variable, regardless of the magnitude of the AP displacement. The natural rubber pad substantially overestimated the balance foam pad by 0.23 mm (or 23%) for every mm increment measured by the balance foam pad (linear regression analysis) [29]. Beyond this, only 5% (1/19) of measurements between the pads did not fall within the limits of agreement. Protocol inconsistencies and surface differences can be ruled out (similar to task-specific postural demand and environmental factors). Therefore, one explanation may be the influence of individual factors specific to that particular subject. Interestingly, even though the natural rubber and foam pads have different textures that may provide different sensory inputs, their maximum compression forces were quite similar. It is possible that the healthy adult subjects were able to sense the difference between the natural rubber and foam pads. However, this may imply that both pads affected postural control in a similar fashion. The natural rubber pad (our sample) and the foam pad (blue foam – Airex®) may, in some instances, be used interchangeably, but with caution.

Limitation

This research demonstrates that a natural rubber pad can be used to assess the balance of healthy individuals. We acknowledge that our research has some limitations. Firstly, the natural rubber pad tested is primarily composed of rubber and latex. Consequently, individuals with allergies to rubber or latex cannot use this balance assessment tool. Secondly, we lacked objective measures of the velocity and displacement of the centre of pressure (COP) in individuals with musculoskeletal or neurological pathologies, and those with abnormal body mass index. Future research should focus on people with postural control-impairing injuries. The natural rubber pad may be beneficial in clinical practice with injured patients; particularly in screening and testing balance deficits with the modified CTSIB (mCTSIB) and BESS tests. However, caution should be considered when examining balance deficits with an unstable support surface, because different pad properties can affect postural sway in different ways.

Conclusions

Similar postural sway was observed between participants standing on balance foam and natural rubber pads, indicating that natural rubber pads can be used as a low-cost balance assessment tool for healthy adults. To clarify the effects of a natural rubber pad on postural control, however, additional research with varying pad properties is required.

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Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Human Research Ethics Committee of Thammasat University (approval No.: COA No.030/2562). This study is listed in the Thai Clinical Trials Registry (ID: TCTR20201215010), clinicaltrials.in.th.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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