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ORIGINAL RESEARCH

Exploring EMG Biofeedback in Core Training – Bosu Ball vs Swiss Ball Efficacy for Collegiate Students with Mechanical Low Back Pain: A Randomized Controlled Trial

Anjali Khanduri[1], Pooja Sharma[1], Nitesh Malhotra[1], Divya Aggarwal[1], Irshad Ahmad[1], Zaheen Ahmed Iqbal[1], Mohammed Mansour Alshehri[2], Ahmad Sahely[2], Mohammad Abu Shaphe[2], Monira I Aldhahi[3]

[1]Department of Physiotherapy, School of Allied Health Sciences, Manav Rachna International Institute of Research and Studies, Faridabad, Haryana, India; [2]Physical Therapy Department, College of Nursing and Health Sciences, Jazan University, Jazan, Saudi Arabia; [3]Department of Rehabilitation Sciences, College of Health and Rehabilitation Sciences, Princess Nourah bint Abdulrahman University, Riyadh, 11671, Saudi Arabia

Correspondence: Zaheen Ahmed Iqbal, Department of Physiotherapy, School of Allied Health Sciences, Manav Rachna International Institute of Research and Studies, Faridabad, Haryana, India, Tel +918447393967, Email Zaheeniqbal.sahs@mriu.edu.in

Purpose: Given the high prevalence of low back pain in this demographic group, effective management strategies are essential. This study aimed to compare the effects of EMG biofeedback-assisted core training using Bosu versus Swiss balls on mechanical low back pain in collegiate students.

Methods: A randomized controlled trial was implemented with 36 participants aged 18–25, randomly assigned to either the Bosu or Swiss ball group. Over four weeks, both groups engaged in specific core strengthening exercises three times a week. Pain intensity, core strength, and functional ability were assessed using the Numeric Pain Rating Scale, Oswestry Disability Index, and EMG analysis, respectively.

Results: Both groups demonstrated significant improvements in pain, functional disability, core strength, and muscle activation following the intervention ($p < 0.05$). No statistically significant differences were observed between the Bosu ball and Swiss ball groups in the primary outcome measures, however, some enhancements were noted in range of motion, muscle activation and functional disability in the Bosu ball group.

Conclusion: EMG biofeedback-assisted core training with Bosu balls is more effective than Swiss balls in managing mechanical low back pain in collegiate students. These findings suggest that incorporating Bosu ball exercises can enhance therapeutic outcomes, underscoring the need for tailored rehabilitation strategies to improve quality of life for young adults suffering from low back pain.

Keywords: low back pain, core strengthening, EMG biofeedback, Bosu ball, Swiss ball

Introduction

Low back pain (LBP) is a significant global health concern, affecting individuals across various age groups and leading to substantial socio-economic costs.[1] Among university students, the prevalence of LBP is particularly high, with lifetime incidence rates reported to be as high as 80%.[2] This demographic is uniquely vulnerable due to a convergence of risk factors such as prolonged sedentary behavior during lectures and study sessions, suboptimal ergonomic conditions, and often insufficient engagement in physical activity.[3] These factors, combined with others like anthropometric characteristics, occupational postures, depressive moods, obesity, and genetic predispositions, contribute to both the development and persistence of LBP in young adults.[2,4]

The management and prevention of LBP are intricately linked to physical activity and muscular endurance. Strengthening exercises for the back, particularly those targeting core musculature, play a crucial role in enhancing

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muscular support for the spine and potentially reducing the incidence of LBP and related disabilities.[5] Mechanical LBP, often classified as non-specific due to its multifactorial nature, arises from improper posture, poor ergonomics, or unsafe lifting techniques, imposing abnormal stress on the muscles supporting the spinal column.[6] This condition is the most prevalent form of muscle dysfunction and is often associated with spinal instability and impaired neuromuscular control. Mechanical LBP affects approximately 20–30% of college students at some point during their studies.[7] This condition can lead to missed classes, decreased academic performance, and reduced participation in physical activities.[8] Core strength and stability are pivotal in the management of LBP. Anatomically, the core encompasses the abdominal muscles anteriorly, the gluteal and paraspinal muscles posteriorly, the diaphragm superiorly, and the hip and pelvic floor muscles inferiorly. Core training aims to fortify and retrain these local skeletal muscles to stabilize the spine effectively.[9] Local muscles, comprising primarily slow-twitch fibers, are responsible for inter-segmental stabilization with minimal force production, while global muscles are involved in generating torque. The weakness and lack of coordination in deep trunk muscles, particularly the multifidus and transverse abdominis, are common in individuals with chronic LBP, leading to reduced proprioceptive sense and spinal stability issues.[10] Therefore, activating deep stabilizer muscles is essential for managing LBP, improving muscle control, and preventing atrophy. The importance of core strength, defined by the strength and endurance of the lumbo-pelvic complex muscles, cannot be overstated. A decrease in core muscle strength reduces spinal stability, leading to LBP and associated disabilities.[11] Core strengthening is crucial for maintaining the functional stability of the lumbar spine and is a significant component of rehabilitation programs.[12] These exercises help reduce pain and disability and enhance general fitness by increasing intra-abdominal pressure, which provides body stiffness and stability.[11]

Research has shown that exercises on unstable surfaces enhance neuromuscular activation and proprioceptive demand, resulting in better outcomes than exercises on stable surfaces.[13,14] Bosu and Swiss balls are popular tools in physical fitness for their ability to challenge the neuromuscular system by providing an unstable environment. The Bosu ball, with its dome shape, offers dynamic instability, whereas the Swiss ball provides multidirectional instability, both of which can lead to greater improvements in balance, proprioception, and muscle engagement.[15] These exercises influence power progression, motor speed, balance, agility, flexibility, accuracy, and coordination, significantly impacting physical performance and promoting physical and functional efficiency.[16]

Unstable surface training using devices such as Swiss balls and Bosu balls has been widely used to enhance core muscle activation and trunk stability. Previous studies have shown that performing exercises on unstable surfaces increases neuromuscular demand, leading to greater activation of abdominal and trunk stabilizing muscles compared to stable surfaces. For instance, trunk stabilization exercises performed on a Swiss ball have been reported to significantly increase activation of key core muscles such as the rectus abdominis, erector spinae, and external oblique.[17] Similarly, research comparing stable and unstable surfaces has demonstrated higher electromyographic (EMG) activity of abdominal muscles during exercises like bridging when performed on Swiss balls or similar unstable platforms.[18] These findings suggest that instability-based training may enhance proprioceptive demands and improve trunk control, making such tools valuable in rehabilitation and conditioning programs.

Incorporating electromyographic (EMG) biofeedback into exercise routines offers a novel approach for optimizing muscle activation.[19] EMG biofeedback provides real-time feedback on muscle activity, enabling individuals to adjust their efforts and focus on specific muscle groups, thereby enhancing the effectiveness of core training.[20] Despite the growing interest in these training modalities, limited research has directly compared the effects of Bosu and Swiss ball exercises with EMG biofeedback on LBP outcomes in collegiate students. Understanding how these differences affect muscle activation and overall outcomes can inform tailored interventions for managing LBP in young adults.

Effective management of LBP in students extends beyond physical health, potentially improving academic performance and reducing healthcare costs associated with chronic pain conditions. This study aimed to compare the effectiveness of EMG biofeedback-assisted core training performed on Bosu versus Swiss balls in collegiate students with LBP, specifically examining differences in pain reduction, core muscle strength, and functional disability outcomes. We hypothesized that both groups would experience benefits, with potential differences in outcomes owing to the distinct characteristics of each unstable surface. By exploring these innovative approaches to core strengthening, this study seeks to contribute valuable insights to the field of physical therapy and rehabilitation. These findings could pave the way for more effective, personalized exercise programs that not only alleviate LBP but also enhance overall physical fitness and quality of life in collegiate students.

Methodology

Study Design

This study utilized a randomized controlled trial design to evaluate the comparative effects of EMG biofeedback-assisted core training using Bosu and Swiss balls on mechanical LBP among collegiate students. Participants were randomly assigned to the Bosu and the Swiss ball groups using a computer-generated random sequence.

Sample Size Calculation

The sample size for this study was determined using G*Power software (version 3.1.9.7, Heinrich Heine-University, Düsseldorf, Germany).[21] Based on previous research conducted by Akisha and Reshma (2019), which indicated an effect size of 0.95 for changes in the Numerical Pain Rating Scale (NPRS) after two weeks of intervention, the sample size required was calculated to be 18 participants per group at a power of 0.8 and an alpha level of 0.05.[22] Therefore, 36 subjects were included in the study, with 18 in each group. Consort flow diagram has been presented as Figure 1.

Participants

A total of 36 collegiate students, aged 18–25 years with mechanical LBP for at least three months, were recruited for the study. Participants were informed about the study's purpose and procedures and provided informed consent forms that

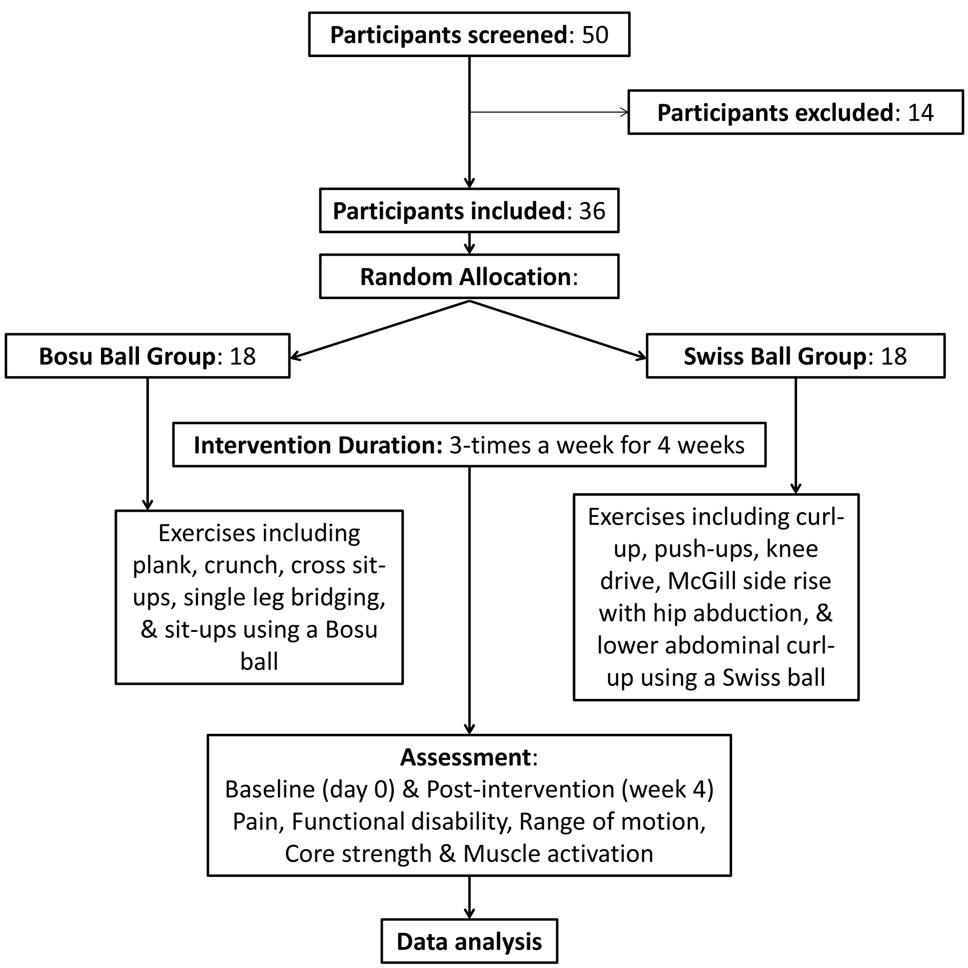

Figure 1 Participant Consort Flow Diagram for EMG Biofeedback-Assisted Core Training Study on Mechanical Low Back Pain in Collegiate Students.

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detailed their rights as research subjects. All participants were assured of confidentiality, and retained the right to withdraw from the study at any time without penalty. Screening ensured that participants met the inclusion criteria, which excluded those with infectious pathologies or injuries within the past six months, those engaged in strength and conditioning programs, individuals with a history of spinal or lower limb surgery within the past six months, and those with evidence of radiculopathy or osteoporosis. Participants were included based on having a normal BMI, NPRS scores between 3–5, and mild-to-moderate functional disability.

Informed Consent Statements and Ethical Approval

All participants were informed about the study's purpose and procedures and had to provide written informed consent before participating in the study. They were assured of confidentiality and retained the right to withdraw from the study at any time without penalty. This study was approved by the Ethics Committee of the Faculty of Allied Health Sciences, Manav Rachna International Institute of Research and Studies, Manav Rachna University, Faridabad, Haryana (MRIIRS/FAHS/PT/2022-23/M-01). All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Intervention Protocols

Participants in the Bosu Ball Group performed exercises including plank, crunch, cross sit-ups, single-leg bridging, and sit-ups using a Bosu ball. The regimen was performed thrice a week for four weeks. In the first two weeks, the participants completed two sets of five repetitions with a five-second hold, progressing to two sets of ten repetitions with a ten-second hold in the third and fourth weeks. In the Swiss Ball Group, participants performed exercises such as curl-ups, push-ups, knee drives, McGill side rises with hip abduction, and lower abdominal curl-ups using a Swiss ball. The exercise protocol mirrored that of the Bosu ball group in terms of frequency and progression.[23,24]

In both groups, EMG biofeedback was integrated into each exercise session using the Delsys Trigno™ wireless EMG system. Real-time muscle activation signals were displayed on a monitor providing visual feedback through a bar graph interface. Participants were instructed to maintain activation within a target threshold zone (60–80% of maximum voluntary contraction) for the relevant core muscles (rectus abdominis and back extensors) during each repetition.The feedback enabled participants to monitor their muscle engagement and make immediate adjustments to maintain consistent activation levels throughout the exercises. No auditory cues were provided. EMG data were simultaneously recorded for analysis.

The exercises selected for both groups were designed to target similar core muscle groups (abdominals and back extensors) while differing only in the type of unstable surface (Bosu ball vs Swiss ball). The progression in repetitions and sets was standardized across groups to ensure comparable training volume and intensity. The variation in exercise modality was intended to examine the influence of different instability conditions on core muscle activation and functional outcomes.

Outcome Measures

EMG data were collected using the Delsys Trigno™ wireless EMG system, which provided real-time feedback during the exercises. EMG sensors were strategically placed to capture muscle activation signals: upper rectus abdominis (3 cm lateral and 5 cm superior to the umbilicus), lower rectus abdominis (3 cm lateral and 5 cm inferior to the umbilicus), upper back extensors (2 cm lateral to the midline of the thoracic spine), and lower back extensors (2 cm lateral to the midline of the lumbar spine).[25]

Maximum voluntary contraction (MVC) testing was performed prior to data collection to normalize EMG signals.[26,27] For the rectus abdominis, participants performed an isometric trunk flexion against resistance, while for the back extensors, an isometric trunk extension task was conducted in a prone position. Each contraction was held for 5 seconds and repeated three times with adequate rest between trials. The highest EMG value obtained was used as the reference for normalization. EMG signals recorded during exercise performance were then expressed as a percentage of

MVC (%MVC) for analysis. EMG was used solely for assessment purposes and not as a biofeedback tool during training.

Pain intensity was assessed using the numeric pain rating scale (NPRS) at baseline and at the end of the intervention period.[28] Core strength was evaluated at 1-minute sit-up test.[29] Functional ability was measured using the Oswestry Disability Index (ODI) to assess functional disability.[30] Lumbar range of motion was assessed using the modified Schober's test.[31]

Statistical Analysis

Data analysis was conducted using the SPSS software (version 13). The Shapiro–Wilk test was used to assess data normality, with the significance set at $p \geq 0.05$. Descriptive statistics were used to determine the means and standard deviations. An independent *t*-test was used to compare data between groups and paired t-tests were used to assess changes within each group. A repeated measure ANOVA was used to examine how outcome measures evolved over time within groups, followed by Tukey's post hoc analysis for detailed insights. Statistical significance was set at $p \leq 0.05$, and results were interpreted within a 95% confidence interval.

Results

Demographic Data

The demographic data of the participants are presented in Table 1, which shows the mean values and standard deviations for age, BMI, height, weight, and pain duration across both groups.

Within-Group Analysis

A dependent *t*-test was conducted to evaluate the effects of core strengthening exercises using Bosu and Swiss balls, assisted by EMG biofeedback, on muscle activation, core strength, and functional ability in collegiate students with from mechanical low back pain. The analysis compared the pre- and post-intervention measurements within each group. The paired *t*-test revealed significant improvements in both muscle activation and core strength, with a p-value of less than 0.001 (Table 2). Additionally, participants in both groups experienced notable enhancements in functional ability, as evidenced by significant reductions in pain levels, functional disability, and improved lumbar range of motion in both flexion and extension ($p < 0.001$).

Between-Group Analysis

An independent sample *t*-test was employed to compare the effects of core strengthening between the Bosu and Swiss ball groups, focusing on muscle activation, core strength, and functional ability measurements. The results, presented in Table 3, demonstrated significant differences between the groups in several key areas. Specifically, muscle activation levels of the flexors, functional disability scores, and lumbar range of motion in both flexion and extension showed

Table 1 Comparative Demographic Data and Statistical Analysis of Participants in Bosu Ball and Swiss Ball Groups. Please Note the Homogenous Distribution Between the Groups

Variables	Bosu Ball Group	Swiss Ball Group	t-value	p-value
Age (years)	20.78 ± 2.07	20.83 ± 2.09	0.080	0.937
Height (cm)	168.06 ± 10.70	165.78 ± 7.03	0.755	0.456
Weight (kg)	63.78 ± 8.64	61.61 ± 5.53	0.896	0.377
Body Mass Index (kg/m^2)	22.50 ± 1.72	22.39 ± 1.13	0.217	0.830
Duration of Pain (months)	4.61 ± 1.14	4.39 ± 1.14	0.582	0.564

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Table 2 Within-Group Analysis of Pre- and Post-Intervention Effects on Pain, Functional Ability, Lumbar Range of Motion, Core Strength, and Muscle Activation Using Dependent *T*-Test

Variables		Group	Pre-Intervention	Post-Intervention	t-value	p-value
Pain (NPRS)		Bosu Ball	4.00± 0.84	1.11±0.75	14.725	<0.001**
		Swiss Ball	3.83 ± 0.78	1.44 ± 0.61	14.524	<0.001**
Functional Disability (ODI)		Bosu Ball	10.78±1.98	4.78± 1.39	22.377	<0.001**
		Swiss Ball	11.22 ± 2.01	6.11 ± 1.56	14.546	<0.001**
Range of Motion (cm)	Flexion	Bosu Ball	6.37± 0.29	7.13± 0.20	16.871	<0.001**
		Swiss Ball	6.40 ± 0.24	6.86 ± 0.19	19.993	<0.001**
	Extension	Bosu Ball	3.50 ± 0.30	4.30± 0.33	16.730	<0.001**
		Swiss Ball	3.54 ± 0.22	3.95 ± 0.18	19.718	<0.001**
Core Strength (number of repetition)		Bosu Ball	19.06± 2.90	24.56±2.93	25.266	<0.001**
		Swiss Ball	17.78 ± 2.51	22.72 ± 2.78	15.548	<0.001**
EMG Biofeedback (%)	Flexors	Bosu Ball	41.67± 5.94	60.56± 6.39	21.893	<0.001**
		Swiss Ball	38.06 ± 4.89	49.72 ± 4.68	20.408	<0.001**
	Extensors	Bosu Ball	33.33± 3.83	45.28 ± 4.01	16.678	<0.001**
		Swiss Ball	32.56 ± 4.68	42.61 ± 4.88	22.171	<0.001**

Note: **p<0.001.

Table 3 Between-Group Comparison of Core Strengthening Effects on Pain, Functional Ability, Lumbar Range of Motion, Core Strength, and Muscle Activation Using Independent Sample *T*-Test

Variables		Group	Bosu Ball	Swiss Ball	t-value	p-value
Pain (NPRS)		Pre-intervention	4.00 ± 0.84	3.83 ± 0.78	0.615	0.543
		Post-intervention	1.11 ± 0.75	1.44 ± 0.61	1.448	0.157
Functional Ability (ODI)		Pre-intervention	10.78 ± 1.98	11.22 ± 2.01	0.666	0.510
		Post-intervention	4.78 ± 1.39	6.11 ± 1.56	2.695	0.011*
Range of Motion (cm)	Flexion	Pre-intervention	6.37 ± 0.29	6.40 ± 0.24	0.306	0.761
		Post-intervention	7.13 ± 0.20	6.86 ± 0.19	4.140	<0.001**
	Extension	Pre-intervention	3.50 ± 0.30	3.54 ± 0.22	0.499	0.621
		Post-intervention	4.30 ± 0.33	3.95 ± 0.18	3.954	<0.001**
Core Strength (number of repetition)		Pre-intervention	19.06 ± 2.90	17.78 ± 2.51	1.414	0.167
		Post-intervention	24.56 ± 2.93	22.72 ± 2.78	1.923	0.063
EMG Biofeedback (%)	Flexors	Pre-intervention	41.67 ± 5.94	38.06 ± 4.89	1.991	0.055
		Post-intervention	60.56 ± 6.39	49.72 ± 4.68	5.799	<0.001**
	Extensors	Pre-intervention	33.33 ± 3.83	32.56 ± 4.68	0.545	0.589
		Post-intervention	45.28 ± 4.01	42.61 ± 4.88	1.789	0.083

Notes: *p < 0.05, **p<0.001.

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significant variations, favoring the Bosu ball group over the Swiss ball group ($p < 0.05$). However, no significant differences were observed in the muscle activation levels of the extensors, pain levels, or overall core strength between the two groups.

Time Effect within the Groups

Repeated-measures ANOVA revealed significant improvements ($p<0.05$) across various outcomes, including NPRS ($p < 0.0010$), ODI ($p < 0.0010$), lumbar flexion ($p < 0.0010$) and extension ($p < 0.0010$) range of motion, core strength ($p < 0.0010$), and EMG activity of flexors ($p < 0.0010$) and extensors ($p < 0.0010$), from pre- to post-intervention in both groups, with the Bosu ball group showing superior enhancements compared to the Swiss ball group (Table 4).

Time × Group Interaction

Though both groups demonstrated significant improvements over time in pain, functional disability, and muscle activation ($p < 0.05$). However, the time × group interaction was not statistically significant ($p > 0.05$) for the primary outcomes, indicating that the magnitude of improvement was comparable between the Bosu ball and Swiss ball groups.

Discussion

The primary aim of this study was to evaluate the effectiveness of core strengthening exercises with EMG biofeedback on unstable surfaces in collegiate students with mechanical LBP. Additionally, this study sought to determine whether Bosu or Swiss ball yields better outcomes. The findings revealed that both intervention groups showed significant improvements in pain reduction, functional ability, and core strength over the four-week period. Although both intervention groups showed significant improvements, the absence of a significant time × group interaction suggests that neither intervention was superior. The observed improvements are likely attributable to the general effects of core stabilization training rather than the specific type of unstable surface used.

Table 4 Repeated Measures ANOVA: Pre–Post Intervention Outcomes in Bosu and Swiss Ball Groups

Outcome	Group	Pre (Mean ± SD)	Post (Mean ± SD)	Time Effect (p, F)	Group Effect (p, F)	Time × Group (p, F)
Pain (NPRS)	Bosu	4.00 ± 0.84	1.11 ± 0.75	<0.001*, 425.0	0.703, 0.148	0.059, 3.814
	Swiss	3.83 ± 0.78	1.44 ± 0.61			
Functional Disability (ODI)	Bosu	10.78 ± 1.98	4.78 ± 1.39	<0.001*, 631.97	0.112, 2.668	0.052, 4.045
	Swiss	11.22 ± 2.01	6.11 ± 1.56			
Lumbar ROM (Flexion, cm)	Bosu	6.37 ± 0.29	7.13 ± 0.20	<0.001*, 581.895	0.113, 2.649	<0.001*, 35.058
	Swiss	6.40 ± 0.24	6.86 ± 0.19			
Lumbar ROM (Extension, cm)	Bosu	3.50 ± 0.30	4.30 ± 0.33	<0.001*, 535.038	0.078, 3.306	<0.001*, 58.363
	Swiss	3.54 ± 0.22	3.95 ± 0.18			
Core Strength (repetitions)	Bosu	19.06 ± 2.90	24.56 ± 2.93	<0.001*, 734.533	0.960, 2.930	0.159, 2.078
	Swiss	17.78 ± 2.51	22.72 ± 2.78			
EMG Flexors (%)	Bosu	41.67 ± 5.94	60.56 ± 6.39	<0.001*, 871.610	<0.001*, 16.703	<0.001*, 48.695
	Swiss	38.06 ± 4.89	49.72 ± 4.68			
EMG Extensors (%)	Bosu	33.33 ± 3.83	45.28 ± 4.01	<0.001*, 673.540	0.226, 1.522	0.033*, 4.965
	Swiss	32.56 ± 4.68	42.61 ± 4.88			

Note: *Significant.

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The significant decrease in pain levels observed in both groups corroborates the findings of previous study that reported that exercises on unstable surfaces enhanced muscular activation compared to stable surfaces.[22] This heightened activation contributes to spinal stability through the coactivation of local and global muscles. This has been supported by demonstrating how core strengthening on unstable surfaces increases abdominal muscle activity, thereby improving muscle co-activation and spinal stabilization.[32] The superior pain reduction in the Bosu ball group aligns with these findings, indicating its effectiveness in engaging more muscle groups due to its unique instability. Functional ability, as measured by the ODI, also improved significantly in both groups, with the Bosu ball group again showing superior results than the traditional group. This is consistent with the findings of Yong-Soo Kong et al (2015), who found a decrease in ODI scores following an eight-week exercise program, highlighting the effectiveness of back exercises in alleviating chronic LBP and enhancing functionality.[33] Studies have also suggested that improved functional ability may result from reduced contact area and increased perturbations, which enhance the control over the center of gravity.[34] The design of the Bosu ball likely accentuates these factors, offering a more challenging and effective exercise experience.

Increased lumbar range of motion in both flexion and extension was another notable outcome, with the Bosu ball group again outperforming the Swiss ball group. Core strengthening exercises enhance movement ease, flexibility, and coordination, as noted in previous studies Suresh et al[35] The inherent instability of the Bosu ball requires greater muscle engagement to maintain balance, likely contributing to superior improvements in range of motion. Both groups showed significant increases in core strength, aligning with the study by Ankita and Amrutkuvar published in 2020, which found improved core strength following a 12-week program on both Bosu and Swiss balls.[16] The flat surface of the Bosu ball provides stability for accuracy, whereas its inflated hemisphere introduces sufficient instability to effectively engage the core muscles. Similarly, the instability of the Swiss ball promotes core engagement as the body works to maintain balance. However, the Bosu ball group showed greater improvements, consistent with Yash and Shwetambari (2022), who concluded that while both surfaces improve core strength, the Bosu ball offers more efficient results.[36]

EMG amplitude improvements in both flexor and extensor muscles were significant in both groups, with the Bosu ball group showing more pronounced gains than the Swiss ball group. EMG biofeedback enhances performance through auditory and visual cues, providing real-time feedback that helps participants adjust and improve their technique. One previous study has highlighted that biofeedback-assisted exercises enhance motor neuron work, improving strength and endurance.[37] The unique challenges of the Bosu ball may better facilitate these biofeedback benefits, resulting in superior muscle activation and functional improvements.

Clinical Implications

This study underscores the benefits of integrating EMG biofeedback into core training, particularly using Bosu balls, for young adults with mechanical low back pain. Bosu balls offer superior effectiveness owing to their instability, which enhances muscle activation and engagement. Practitioners should tailor rehabilitation programs to individual preferences and goals to optimize outcomes and ensure the proper form. Both Bosu and Swiss ball exercises improve core strength and functional ability, but Bosu balls may provide additional benefits.

Limitations and Future Studies

This study had several limitations, including the lack of a control group and potential variability in participants' adherence to the exercise protocol, which may have affected the reliability of the results. The short duration might not reflect long-term outcomes, and self-reported pain measures could have introduced bias. Additionally, the unequal male-to-female ratio and the absence of follow-up assessments limit the generalizability of the findings. Future research should incorporate a control group and extend the study duration to evaluate the long-term effects. Comparing male and female responses could offer insights into gender-specific rehabilitation strategies, and a larger sample size would enhance the study's robustness. Future research should explore these differences further to refine core strengthening programs, highlighting the need for innovative and adaptable strategies in managing mechanical low back pain.

Conclusion

The results of this study show that both Bosu ball and Swiss ball training programs were effective in improving pain, functional disability, core strength, and muscle activation in individuals with mechanical low back pain. However, no statistically significant differences were observed between the two groups for the primary outcomes, indicating comparable effectiveness of both interventions. Bosu ball group demonstrated slightly greater improvements in certain secondary measures such as muscle activation and flexibility. Overall, unstable surface training, irrespective of the device used, appears to be beneficial in the rehabilitation of mechanical low back pain.

Declaration of Generative AI

This work utilized CHATGPT for paraphrasing and language editing in initial drafts. The output was subsequently reviewed and revised before final submission.

Data Sharing Statement

Data is available from the corresponding author on a reasonable request.

Ethical Approval

This study involved an interventional design but was conducted as part of a student research project. As such, prospective trial registration was not performed due to institutional limitations and the educational nature of the work. The study was, however, approved by the Institutional Ethical Committee (MRIIRS/FAHS/PT/2022-23/M-01), and all procedures adhered to relevant ethical guidelines.

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Disclosure

The authors report no conflicts of interest in this work.

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