

Effects of Wearing A Non-Elastic Lumbar Brace on Gait, Balance, and Squat Performance

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Abstract

Purpose: This study aimed to investigate the immediate effects of wearing non-elastic and elastic lumbar orthoses (LSO) compared to a no-brace condition on gait, balance, and squat performance in healthy adults.

Methods: In a randomized crossover design, eighteen healthy adults completed three conditions—non-elastic LSO, elastic LSO, and no LSO. Static balance was assessed once using a foam, eyes-closed Romberg test; dynamic balance was evaluated with the Limits of Stability (LOS) test from two trials averaged. Gait was measured on a treadmill with OptoGait at each participant's self-selected speed after 2-min familiarization, capturing 30-s of continuous data. Squats to ~90° knee flexion were performed 5 repetitions per condition with 2-min rests between conditions, while EMG of the rectus femoris and semitendinosus was recorded during the task.

Results: No significant differences were found in gait or balance parameters across the three conditions. However, the non-elastic LSO significantly increased the mean and peak muscle activation of the Rectus Femoris compared to the elastic brace and no-brace conditions. In contrast, the elastic LSO significantly increased muscle activation variability (instability) compared to the non-elastic brace.

Conclusions: The non-elastic LSO did not show immediate benefits for low-level tasks but enhanced the recruitment of the Rectus Femoris muscle during the high-coordination squat exercise. The results of this study suggest that the non-elastic LSO induces joint moment redistribution, leading to increased quadriceps femoris muscle activity during high-load functional tasks.

Keywords: Non-elastic lumbar LSO, Elastic LSO, No LSO, Balance, Gait, Squat.

1. Introduction

Spinal stabilization is emphasized for the effective prevention and management of low back pain (LBP) in modern society. According to World Health Organization statistics, approximately 619 million people worldwide experienced LBP in 2020, and this figure is projected to increase to about 843 million by 2050 with population growth and aging [1]. With the expansion of the older adult population, the prevalence of LBP is expected to rise further. Various approaches have been proposed to enhance spinal stability; among them, the lumbosacral orthosis (LSO) has been suggested as a popular and effective means of improving lumbar alignment [2]. Proper spinal alignment not only reduces LBP but also contributes to overall balance capacity. Jung et al. (2020) reported that improving trunk stability significantly enhances functional movement and dynamic balance in individuals with chronic LBP [3].

Dynamic balance plays a crucial role during gait, which typically consists of the swing and stance phases. In this process, the foot establishes a new base of support (BOS), while movement of the center of mass (COM) is controlled to maintain stability. Remelius et al. (2014) reported that when the foot moves ahead of the COM to form a new BOS, walking stability improves; conversely, when the COM departs the BOS first, instability increases—underscoring that anticipatory foot placement to establish a new BOS is essential for dynamic balance [4].

When dynamic balance declines, the risk of falls in daily life increases and may lead to serious injury. Securing dynamic balance is therefore critical for fall prevention and the maintenance of functional independence [5,6]. Trunk stability—the body's central stabilizer—resists external forces and regulates postural control, thereby helping to maintain balance; wearing an orthosis can increase postural stability and enhance balance sensation. In related work, Kader et al. (2024) found that LSO use improved postural stability and balance control and significantly enhanced gait rhythm, speed, precision, and cycle duration [7].

Maintaining trunk stability requires both trunk and lower-limb strength. Lower-limb strength supports the body and drives movement, and is particularly important for sit-to-stand, a common activity of daily living. Among exercises that effectively train movement, the squat is efficient for concurrently strengthening the trunk and lower limbs [8,9]. Slater (2017) reported that during squats the hamstrings, quadriceps, and gastrocnemius act as primary movers and stabilizers, and that maintaining intra-abdominal pressure (IAP) is necessary for postural stability [10]. When trunk strength is insufficient or IAP is reduced and stability declines, wearing an LSO can increase IAP and facilitate trunk muscle contraction, thereby raising mechanical stiffness

and improving overall stability [11] .

According to Ludvig et al. (2019), non-elastic LSOs increase lumbar stiffness and enhance spinal stability without excessive co-contraction of the abdominal and back muscles; this may help protect the lumbar spine during high-load tasks such as squats [12] . By limiting pelvis–trunk motion, non-elastic LSOs can redistribute joint moments and promote focused use of the lower limbs, increasing activation of the quadriceps and hamstrings. Sang-Cheol Im et al. (2022) reported that wearing a non-elastic LSO positively affected joint-angle control and muscle recruitment patterns and increased anterior pelvic tilt [13] . Likewise, Tröster et al. (2022) reported that a back-support exoskeleton increased lower-limb muscle use during squat tasks, with significant trends toward greater activation of the quadriceps and hamstrings [14] .

However, reported effects of LSOs differ according to material extensibility and structural design, and findings comparing elastic and non-elastic LSOs are mixed. Elastic LSOs encircle the abdomen and trunk to provide stability while permitting movement, which may positively influence postural control and proprioception. For example, Kang et al. (2016) found in patients with chronic LBP that elastic LSOs produced greater improvements in anteroposterior balance indices (API) and pain (VAS) than non-elastic LSOs [15] . Choo (2020) further reported psychological reassurance, pain relief, and gait improvement with elastic LSOs [16] . In contrast, Boucher et al. (2017) compared orthosis effects on proprioception in both LBP patients and healthy adults and found no significant changes in repositioning error (constant/absolute error) regardless of brace type, expressing skepticism about sensory benefits [17] .

Non-elastic LSOs primarily restrict spinal motion and provide localized stability, thereby reducing spinal loading and contributing to pain relief. Bai et al. (2023) reported that non-elastic LSOs increase IAP, enhance spinal stability, and effectively reduce pain and improve function, with particularly meaningful effects on dynamic rather than static stability [18] . Similarly, Azadinia et al. (2019) reported that wearing a non-elastic LSO reduced anteroposterior sway amplitude and improved postural stability [19] . Choo (2020) also reported pain relief, postural correction, and improved stability with non-elastic LSOs [16] . Conversely, Shahvarpour et al. (2019) found that non-elastic LSOs decreased the complexity and increased the predictability of postural sway, potentially inducing less adaptable postural-control strategies and thereby reducing dynamic balance control [20] .

Given these heterogeneous findings—and the relative scarcity of studies directly comparing elastic LSO, non-elastic LSO, and no-brace conditions during functional tasks—this study seeks to overcome limitations of simple pre–post designs by comparing three conditions (elastic LSO, non-elastic LSO, and no LSO) to objectively evaluate their immediate effects on performance in balance, gait, and squat tasks.

II. Materials and Methods

2.1. participants

This study involved eighteen healthy adults in their twenties who were enrolled at S University in Asan. The inclusion criteria were: (1) men and women aged 20 years or older; and (2) individuals who voluntarily agreed to participate in the study. The exclusion criteria were as follows: (1) individuals with neurological disorders; (2) individuals with conditions that affect posture; (3) individuals with degenerative diseases; (4) individuals who had experienced a musculoskeletal disorder within the past 6 months; (5) individuals with psychiatric disorders; (6) individuals with dermatologic disease involving the abdomen or lumbar region; and (7) individuals whose underweight or overweight status made brace wear difficult [Table 1].

Table 1. General characteristics of participants

Variables	Group(n=18)
Height(cm)	171.94±9.03
Weight(kg)	66.63±17.70
Age(years)	21.56±1.75

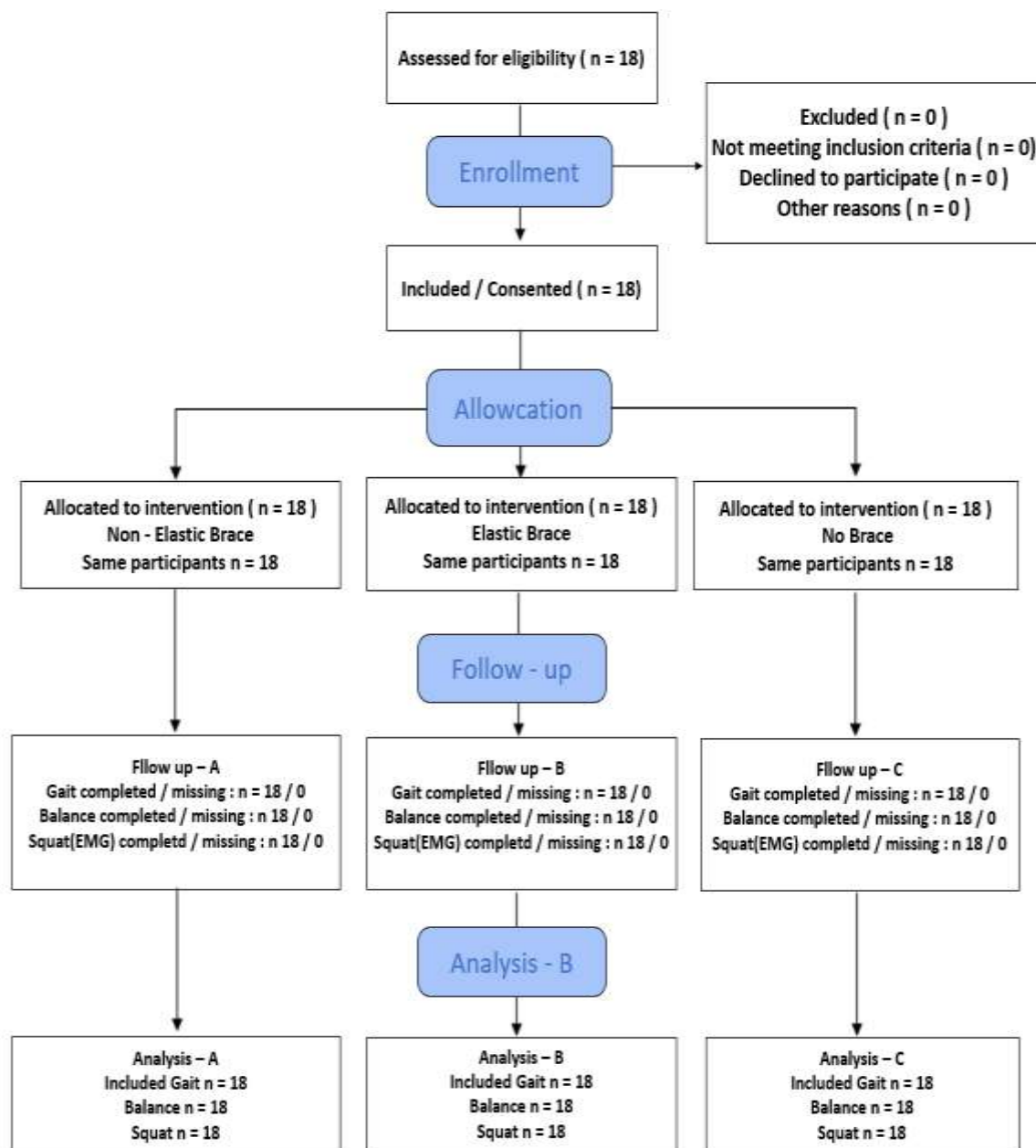
2.2. Experiment procedures

The general characteristics of the participants—age, height, and weight—were collected once, and the participants scheduled the experiment with the researcher in advance. Before participating in the experiment, they received instruction on the experimental equipment and underwent a single test measurement. The subjects performed tasks to assess static and dynamic balance ability, to measure gait ability, and to evaluate squat muscle activity under the Non-elastic LSO, Elastic LSO, and No LSO conditions in a randomized order.

Static balance ability was evaluated under the Romberg condition—standing on an irregular foam surface with eyes closed—and

a 30-second rest was provided for each condition. Dynamic balance ability was evaluated using the Limits of Stability (LOS) test, and the corresponding values were measured twice and averaged. Gait analysis was conducted by installing the OptoGait system on a treadmill. The treadmill speed was set to the participant's usual walking speed, and after 2 minutes of familiarization walking prior to exercise, 30 seconds of continuous walking data were recorded. For lower-limb strength measurement, squats were performed; following the researcher's verbal cue, the participants descended slowly to a 90-degree knee-flexion position and then returned to standing. Each condition was measured five times, with a 2-minute rest provided between conditions, and EMG electrodes were attached to the rectus femoris and semitendinosus to measure muscle activity of those muscles [Figure 1].

Figure 1. Experiment procedures



2.3. Measurement Tools and Methods

2.3.1. Non-elastic lumbar orthosis

The Non-elastic LSO used in this study consisted of a posterior main body with a rigid frame structure, bilateral vertical stays, and

an anterior fastening unit, and combined non-extensible composite-resin and fabric panels with breathable mesh. The purpose of the brace was to mechanically restrict lumbar flexion, extension, lateral bending, and rotation; a buckle-type tightening device allowed length adjustment so that non-elastic tension could be maintained consistently to fit the wearer's body shape. As a result, trunk stiffness during activity is increased and maintenance of lumbar alignment during activity is assisted. Prior to the experiment, participants were instructed in the proper donning method under the guidance of a trained researcher [Figure 2].

Figure 2. Non elastic brace



2.3.2. Elastic-lumbar orthosis

The Elastic LSO was made of neoprene or other highly elastic materials, with flexible posterior reinforcement stays inserted to provide compression and light support. On the front, Velcro straps were used: a primary strap that wraps around the waist and a secondary strap that can adjust trunk stiffness. Tension was adjusted to the body shape, and—by virtue of the elastic material—it permitted movement while attenuating small oscillations through abdominal compression and pressure distribution. It did not mechanically and strongly restrict joint range of motion. Prior to the experiment, participants were instructed in the proper donning method under the guidance of a trained researcher [Figure 3].

Figure 3. Elastic brace



2.3.3. Physiosensing

2.3.3.1. Romberg test

To verify the immediate effect of brace wear on static balance, the Romberg test was performed. To control visual and spatial sensory dependence, the test was conducted for 30 seconds on an irregular foam surface, and the visual condition was measured under the Eye close condition. By removing visual information and thereby assessing plantar proprioceptive feedback, we aimed to identify changes in trunk stabilization and postural correction strategies due to brace wear. In all conditions, variability of the center of pressure (COP) was examined, and to determine how widely the COP swayed, the sway range was set as the ellipse area, and the sway speed within that area was set as the mean COP velocity, to compare the effects of brace wear [Figure 4].

2.3.3.2. Limit of Stability (LOS) test

To verify the immediate effect of brace wear on dynamic balance, the LOS test was performed. While looking at the targets presented on the screen and without lifting the feet, the center of pressure (COP) was moved as far as possible in eight directions (front, front-right, right, back-right, back, back-left, left, front-left), and posture was maintained at the point of maximum reach. The order of the directions followed the system's progression in a clockwise sequence. The task was performed twice, and the average value was used. The measurement parameters included Endpoint Excursion, representing the maximum reach distance to the target, and Directional Control, evaluating the degree of control over unnecessary movements [Figure 5].

Figure 4. Romberg test



Figure 5. LOS test



2.3.3.3. Optogait

Gait analysis was performed by installing the OptoGait system on a treadmill. OptoGait consists of bars that transmit and receive light and is used to measure spatiotemporal gait data. Each bar is 1 m in length, and the bars are placed in parallel and contain 100 light-emitting diodes that transmit continuous signals. Participants were measured at their average (self-selected) walking speed after 2 minutes of adaptation walking, during which 30 seconds of continuous gait data were recorded; for accurate measurement, shoes were not worn. The gait variables measured were Step Length, Stride Length, Stance Phase, and Cadence [Figure 6].

2.3.3.4. Squat Test

Participants stood with both feet shoulder-width apart, placed flat on the floor, maintained neutral spinal posture and pelvic alignment, and kept the arms gathered in front of the chest. The procedure was conducted according to the researcher's verbal cues, and each condition (Non-elastic LSO, Elastic LSO, No LSO) was performed five times, with a 2-minute rest between conditions. The conditions were performed after two practice sessions prior to the experiment. Surface EMG for the squat task was attached to the rectus femoris and semitendinosus to collect data on mean muscle activity during the movement, instability of muscle activity, and peak muscle activity [Figure 7].

Figure 6. Optogait



Figure 7. Squat test



2.4. Data Analysis

Statistical analyses were performed using SPSS Statistics 31.0, and normality for all parameters was examined with the Shapiro–Wilk test. As a result, normality was satisfied under all conditions ($p > 0.05$). To analyze differences among the three conditions (non-elastic lumbar brace, elastic lumbar brace, and no brace), a one-way ANOVA was conducted, and the significance level for all analyses was set at $p < 0.05$.

III. Results

In this study, OptoGait (gait), PhysioSensing (balance), and Free EMG-1000 (squat) were used to compare, by one-way analysis of variance (one-way ANOVA), the gait, balance, and squat parameters of the same participants under three conditions: non-elastic lumbar brace, elastic lumbar brace, and no brace. The results by domain are as follows.

3.1. Comparison of Gait Parameters Across Three Conditions

In an experiment using OptoGait with eighteen participants across three conditions, no statistically significant differences were found among the three conditions in the gait parameters of the same participants—such as step length, stride length, stance phase, and cadence ($p > 0.05$)[Table 2].

Table 2. Comparison of Spatiotemporal Gait Parameters Across Lumbar Orthosis

Region	Non elastic brace	Elastic brace	No brace	F	p
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Step length(cm)	Left	51.38±19.82	51.53±19.77	51.36±20.31	0	1
	Right	52.14±20.81	51.54±19.84	51.96±20.76	0.004	0.99
Stride length(cm)		103.67±40.48	103.26±39.92	103.29±40.36	0.001	0.99
Stance phase(%)	Left	52.14±9.62	49.64±9.72	50.32±9.14	0.333	0.71
	Right	52.37±9.44	51.99±10.55	53.13±11.41	0.055	0.94
Cadence(step/min)		89.88±22.67	86.44±23.10	85.61±23.47	0.173	0.84

*p<.05, **p<.01, ***p<.001, Mean±SD

3.2. Comparison of Balance Parameters Across Three Conditions

Additionally, in experiments using PhysioSensing for the Romberg test and LOS test across the three conditions, no significant differences were found among the three conditions in the balance parameters of the same participants—such as Ellipse area, COP velocity, Endpoint Excursion, and Directional Control ($p > 0.05$)[Table 3].

Table 3. Comparison of Balance Parameters Across Lumbar Orthosis Conditions

Region	Non-elastic brace	Elastic brace	No brace	F	p
Foam- Eyes Close Ellipse area	130.82±82.27	127.36±86.43	173.30±151.88	0.94 7	0.39
Foam- Eyes Close Mean COP velocity	12.80±13.37	9.33±2.86	9.48±2.93	1.06 1	0.35
Endpoint Excursion	545.20±147.43	547.20±146.38	365.99±136.41	0.09 3	0.91
Directional Control	72.89±7.39	880.15±235.53	496.44±179.51	1.00 5	0.37

*p<.05, **p<.01, ***p<.001, Mean±SD

3.3. Squat Electromyography comparison across three conditions

In contrast, when comparing the squat indices between the non-elastic brace condition and the elastic brace condition, the non-elastic brace condition showed a statistically significant increase in the mean muscle activity during movement of the rectus femoris compared with the elastic brace condition ($p < 0.05$), whereas the elastic brace condition showed a statistically significant increase in the instability of muscle activity compared with the non-elastic brace condition ($p < 0.05$). In addition, when peak muscle activity was compared between the non-elastic brace and no-brace conditions, peak muscle activity was significantly higher in the non-elastic brace condition ($p < 0.05$)[Table 4].

Table 4. Comparison of Squat Electromyography Parameters Across Three Conditions

Region		Non-elastic brace	Elastic brace	No brace	F	p
Rectus femoris	total mean m	210.70±47.91 ^a	162.24±53.21 ^a	191.1±56.99	3.831	0.03
	total mean s	146.21±27.17 ^a	175.91±11.08 ^a	160.4±45.06	4.118	0.02
	peak	394.28±75.83 ^b	361.63±59.27	332.1±65.75 ^b	3.844	0.03
Semi tendinosus	total mean m	58.15±44.66	48.32±14.42	46.71±12.42	0.878	0.42

total mean s	29.87±35.45	22.46\5±14.18	20.4±11.11	0.849	0.43
peak	120.66±111.73	101.89±53.86	91.3±34.96	0.718	0.5

* a means difference between Non elastic brace and Elastic brace, b means difference between Non Elastic brace and no brace, *p<.05, **p<.01, ***p<.001, Mean±SD

IV. Discussion

In this study, we experimentally compared changes in parameters for gait, balance, and squats across the conditions of non-elastic lumbar brace, elastic lumbar brace, and no brace in healthy adults. We hypothesized that wearing a non-elastic brace would increase dynamic stability, adjust body alignment, and enhance lower-limb muscle activity, thereby producing changes in gait, balance, and squat performance. However, contrary to the hypothesis, our gait and balance results showed no differences and exhibited trends similar to previous studies.

For gait, no significant changes were observed in step length, stride length, cadence, or stance phase. One study reported by Hekmatfard et al. (2021) found that adding a non-elastic brace in a randomized clinical trial did not produce changes in gait-system complexity [21]. In addition, Song et al. (2016) argued that under level-ground walking conditions, the effects of brace wear are task-dependent and immediate changes are limited [22]. Another study by Keshavarzi and Arazpour (2024) concluded that lumbar braces do not consistently improve temporal or spatial gait indices, suggesting that the gait effects of braces may be limited depending on task and population context [23]. Based on these prior findings, the lack of statistically significant gait results in the present study can be interpreted as reflecting (i) the high baseline performance level of healthy adult participants even when wearing non-elastic and elastic braces, (ii) the low task difficulty of level-ground walking, and (iii) the immediate application with a short adaptation period, under which step length, stride length, cadence, and stance phase did not change.

For balance, no significant changes were observed in Ellipse area, COP velocity, Endpoint Excursion, or Directional Control. In prior balance research, Shahvarpour et al. (2019) reported that both non-elastic and elastic braces tend to make balance control less adaptive under unstable conditions [20]. This phenomenon can be interpreted such that, in the case of a non-elastic lumbar brace, increasing passive trunk stiffness and restricting range of motion reduce the degrees of freedom needed for fine balance control, thereby potentially lowering stability; in the case of an elastic lumbar brace, variable support may alter balance strategies and muscle coordination such that exploration of new movement strategies leads to instability. Additionally, De Oliveira et al. (2022) argued that immediate application of an LSO did not significantly improve balance [24], and Azadinia et al. (2017) reported that a four-week randomized trial did not confirm a balancing effect of the LSO [25]. In light of these prior studies, the absence of statistically significant balance findings in the present study may be interpreted as follows: for the non-elastic LSO, range-of-motion restriction due to increased stiffness reduced the degrees of freedom in postural-control strategies (e.g., ankle and hip strategies); for the elastic LSO, variable support may have prompted participants to temporarily explore new movement strategies or to readjust muscle coordination, such that stability did not improve immediately.

By contrast, for the squat task, prior studies on brace use suggest that increases in trunk stiffness and intra-abdominal pressure are reflected immediately in movement strategies, with reports of increased core and lower-limb muscle activation, suppression of lumbar segmental motion, and simplification of movement strategies. In the present study, to verify increased lower-limb muscle activation, we used the Free EMG-1000 to analyze mean muscle activity during the movement, instability of muscle activity, and peak muscle activity. Under the non-elastic orthosis condition, mean muscle activity during the movement and peak muscle activity were significantly increased, whereas under the elastic orthosis condition, instability of muscle activity was significantly increased. This can be interpreted as the non-elastic lumbar brace maintaining intra-abdominal pressure through consistent compression and increased trunk stiffness, suppressing micro-movements of the trunk and pelvis, simplifying load paths, and relatively increasing the requirement for knee extension. Among prior studies, Joseph et al. (2020) reported that manipulation of trunk stabilization or changes in load paths through a brace emphasize the need for lower-limb strength [26], and Straub and Powers (2024) reported that as the trunk becomes more upright, the knee-flexion moment increases while the hip-flexion moment decreases [27]. This suggests that with a reduced hip-flexion moment, the contribution centered on hip extension decreases relatively, and the contribution by the rectus femoris may increase.

In contrast, with the elastic lumbar brace, instability of muscle activity increased significantly. This can be interpreted as variable support allowing relatively greater freedom in fine stabilization and co-contraction control during performance, thereby increasing strategy exploration during repeated movements. In another study, Anders and Hübner (2019) reported that an elastic lumbar brace does not induce uniform increases or decreases in trunk muscle activity but produces transient recoordination with

muscle-specific changes [28]. Thus, differences in brace extensibility lead to differences in kinematics and movement strategies; in related prior work, Sang-Cheol Im et al. (2022) reported that differences in extensibility between non-elastic and elastic lumbar braces affect segmental kinematics and muscle activation in tasks such as sit-to-stand [13]. Based on these prior studies, non-elastic braces appear to reduce trunk degrees of freedom and simplify force-transmission paths through increased trunk stiffness and consequent restrictions in movement angles, thereby increasing quadriceps activation and, consequently, rectus femoris activation. By contrast, elastic lumbar braces, via variable support, appear to increase the freedom of coordination strategies and induce changes in movement strategies that raise the instability of muscle activity, an effect that may be more pronounced in tasks with high load and coordination demands.

In this study, we applied three conditions—non-elastic lumbar brace (LSO), elastic LSO, and no brace—to the same participants and compared the immediate effects on balance, gait, and squats in healthy adults. While condition-dependent changes were limited in balance and gait indices, Free EMG-1000 analyses during squats suggest that, with non-elastic brace wear, increased trunk stiffness, maintenance of abdominal pressure, and restriction of lumbar and pelvic motion reduce compensations and relatively increase the requirement for knee extension, contributing to increases in the rectus femoris' mean and peak muscle activity during squats [26,27]. In other words, the non-elastic brace partially redistributes joint moments at the hip and knee, making mean and peak muscle activity during squats more pronounced; thus, effects emerge in movements with high load and coordination demands, such as squats. By contrast, the elastic brace allows relatively greater freedom in fine stabilization and co-contraction control during performance, increasing strategy exploration during repeated movements and thereby raising the instability of muscle activity—an effect that appears more salient in tasks with high load and coordination demands [28].

This study has several limitations. First, the sample size was limited, which restricts the generalizability of the findings. Second, although typical older adults often present with factors such as low back pain, reduced step length, and decreased balance, our experiment was conducted with healthy adults; therefore, differences related to brace wear did not emerge. Accordingly, there are limitations to interpreting the results as long-term effects of brace use. Future research should increase the sample size and reduce experimental error—for example, by recruiting older adults rather than healthy young adults and refining the experimental procedures.

V. Conclusions

This study aimed to verify the effect of a non-elastic brace by measuring gait, balance, and squat performance across three conditions: non-elastic brace, elastic brace, and no brace. The results showed that, when wearing the non-elastic brace, no significant differences were observed among conditions in gait parameters or balance parameters.

By contrast, during the squat task, wearing the non-elastic lumbar brace increased mean muscle activity during the movement compared with the elastic brace condition, and increased peak muscle activity compared with the no-brace condition. Conversely, when wearing the elastic brace, instability of muscle activity increased significantly compared with the non-elastic brace condition. In other words, while the non-elastic brace did not show immediate significant effects on gait and balance parameters, it appears to be associated with increased activation of the rectus femoris in functional tasks with high load and coordination demands, such as squats. However, generalization of these findings is limited by the healthy sample and short-term application; therefore, follow-up studies are needed that include careful participant selection, longer adaptation, and a range of task difficulties.

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