Original Article

HEALTH SCIENCES
MEDICINE

DOI: 10.32322/jhsm.1193371
J Health Sci Med 2023; 6(1): 59-65

Reciprocal activation changes of lower extremity muscles caused by the abdominal hollowing maneuver in patients with unilateral lumbar disc herniation: an electromyography study

Ceyhun Türkmen[1], Aysenur Özcan[1], Zehra Can Karahan[1], Ismail Bozkurt[2]

[1]Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Çankırı Karatekin University, Çankırı, Turkey
[2]Department of Neurosurgery, Medical Park Ankara Hospital, Ankara, Turkey

Cite this article as: Türkmen C, Özcan A, Can Karahan Z, Bozkurt İ. Reciprocal activation changes of lower extremity muscles caused by the abdominal hollowing maneuver in patients with unilateral lumbar disc herniation: an electromyography study. J Health Sci Med 2023; 6(1): 59-65.

ABSTRACT

Aim: Decreased or delayed multifidus and transversus abdominis (TrA) activity, transition of the TrA from tonic to phasic activity, and increased activity in the more superficial erector spinae muscles are behaviors unique to people with lumbar disc herniation (LDH). This study investigates whether the abdominal hollowing maneuver (AHM), which activates the TrA, can improve the rates of impaired muscle reciprocal activation of the lower extremities due to unilateral LDH during walking, tandem walking, and stair climbing activities.

Material and Method: The healthy and affected lower extremities of 17 patients with unilateral LDH were analyzed. The participants performed three activities and three times without the AHM. For the walking activity, the participants took a total of eight steps without deviating from their normal gait pattern. For the tandem walking activity, the participants covered the eight-step distance by performing heel-to-toe walking. For the stair climbing activity, the participants climbed a total of four steps without support from their upper extremities. The researchers visually checked the postures of the participants during all stages of the activities. The ratio of tibialis anterior (TA) and medial gastrocnemius (MGC) electromyographic values that emerged during the activities to the maximum voluntary isometric contraction (MVIC) values of these muscles was called MVIC%. Then the MVIC% values of the TA and MGC were matched, and the muscle reciprocal activation ratio ("MVIC%"-TA/"MVIC%"-MGC) was determined. While the activities were being performed, the MVIC% values of both muscles were measured separately without and with the AHM.

Results: Reliability values ranged from 0.87 to 0.99, with an SEM of 2.22 to 11.98. The ICC3,1 was considered "good" or "excellent" for all muscle surface electromyography measurements. During the tandem walking activity performed with the AHM, the reciprocal activation rates of TA: MGC on the affected and healthy legs converged (p=0.010, d=0.71). However, TA: MGC reciprocal activation rates did not differ between the affected and healthy extremities in the walking (p=0.519, d=0.16) or stair climbing (p=0.180, d=0.35) activities performed with the AHM.

Conclusion: According to the results of the study, integration of the AHM into tandem walking activity brought the reciprocal activation rates of both legs closer to each other and enabled them to exhibit similar behaviors, even without adherence to any exercise protocol. Therefore, tandem walking can be selected as an appropriate activity to combine with spinal stabilization exercises performed by unilateral L4-L5 radiculopathy patients using the AHM along with the task.

Keywords: Abdominal hollowing maneuver, disc herniation, lower extremity muscles, surface electromyography, tandem walking

INTRODUCTION

Lumbar disc herniation (LDH) is a spinal degenerative disorder that can cause low back and leg pain, loss of muscle strength, and functional impairment in adult and middle-aged populations (1,2). In the symptomatic treatment of LDH, noninvasive or minimally invasive methods should be considered primarily (3). Physical and behavioral therapy, medication, and interventional therapy are noninvasive or minimally invasive methods used for the treatment of LDH (4). Physical and behavioral therapy techniques used in the management of LDH consist of exercise (5), traction (6), manual therapy (7), electrotherapy (8), and heat interventions (9), from a high to a low evidence level, respectively.

Spinal stabilization exercises are a commonly used method for low back pain (LBP) management (10). Muscular imbalance of the lumbopelvic region puts excessive pressure on the vertebrae and can lead to LBP Abdominal hollowing maneuver (AHM) and abdominal bracing maneuver (ABM) are commonly used to stabilize the trunk (11). AHM is a method of selectively contracting the transverse abdominis muscle and internal oblique abdominis (IO). ABM increases the stability of the vertebrae against sudden perturbations and reduces the movement of the lumbar spine (12). Decreased or delayed multifidus and transversus abdominis (TrA) activity, transition of the TrA from tonic to phasic activity, and increased activity in the more

Corresponding Author: Ceyhun Türkmen, fztceyhunturkmen@gmail.com
Received: 23.10.2022 **Accepted:** 22.11.2022

superficial erector spinae muscles are behaviors unique to people with LBP (12, 13). The AHM is commonly used to increase spinal stability (14). The AHM activates the TrA and internal oblique muscles and minimizes the activity of the more superficial muscles (15).

In patients with unilateral LDH, phasic rather than tonic activity is observed in the TrA and multifidus muscles, which can be activated by the AHM (16). Activation of the TrA, multifidus, and pelvic floor muscles with the AHM provides lumbopelvic motor control by stabilizing the spine, hips, and lower extremities during movement. Thus, it is thought that deterioration in the reciprocal activation of the muscles working with agonist/antagonist activity due to muscle weakness in the lower extremity caused by LDH can be fixed by using the AHM alone, without any intervention in the related muscle. (12).

Previous studies have shown that AHM can affect lower extremity muscle activations. Kim et al. (14) suggested that AHM and ABM performed during side-lying hip abduction would increase pelvic stabilization. In another study, Lee examined the effects of three different abdominal maneuvers during different lower extremity activities and showed that both AHM and ABM increased lumbar stabilization (17). Enjuoo et al. (15) investigated the effect of the AHM on pelvic rotation during straight leg lifting activities and suggested that the AHM should be used to provide lumbopelvic stabilization. Although the current literature aims to examine the rotation angles of abdominal maneuvers to increase stabilization, it has been frequently assumed in recent years that these maneuvers can change the muscle activation rate of the trunk and lower extremities. Harput et al. (18) found that the rate of abdominal coactivation would affect lower extremity activation during functional exercises. Park et al. (19) similarly observed that AHM changed the activity of both trunk and quadriceps femoris muscles. Ennis et al. (20) investigated the effects of the ABM on gastrosoleus and tibialis anterior (TA) contraction rates and reported an increase in gastrosoleus activity on moving surfaces and tibialis anterior activity on stable surfaces. Although there has been an increase in studies examining the relationship between muscle activation rate and abdominal maneuvers in recent years, these studies are generally experimental studies performed in healthy individuals. There are no studies in the literature suggesting which exercise is appropriate for problems that prevent activation of lower extremity muscles, such as LDH, especially during the exercise stages where return to daily life activities are planned. Therefore, the aim of the present descriptive laboratory study was to investigate whether the isolated AHM could compensate for functional impairments caused by tibialis anterior muscle weakness due to unilateral L4-L5 disc herniation. We hypothesized that individuals with unilateral L4-L5 LDH would increase the reciprocal activation rate of the TA and medial gastrocnemius (MGC) muscles on their affected sides with the isolated AHM during walking, tandem walking, and stair climbing activities and that it would become similar to the rate on their healthy sides. In this way, it will be revealed which of the activities of daily living will be more beneficial when combined with AHM.

MATERIAL AND METHOD

The study was carried out with the permission of Çankırı Karatekin University Faculty of Health Sciences Ethics Ethics Committee (Date: 09.11.2021, Decision No: 23). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

Participants

Between February and June 2022, 17 subjects with LDH (6 females, 11 males; Age: 50.613.9 years BMI: 27.67.1) voluntarily participated in the study. (**Table 1**). The healthy and affected lower extremities of seventeen subjects with a diagnosis of unilateral LDH were analyzed. All measurements were performed at Çankırı Karatekin University, Physiotherapy and Rehabilitation Laboratory. The inclusion criteria were a diagnosis of unilateral protrusion by a neurosurgeon and a diagnosis confirmed by magnetic resonance imaging (MRI) reports. Disc herniations requiring surgical intervention and cases with bilateral herniations were excluded from the study. All participants provided informed consent before enrollment.

The sample size was calculated using G*Power 3.1 software (21). The effect size (dz) was calculated as 1.88 based on the changes in muscle activation patterns reported in a study by Nelson-Wong et al. (22) . The results of power analysis indicated that to detect improvement with α=.05 and β=90%, the estimated sample size was 16.

Procedures

Surface EMG (sEMG) Measurement Protocol: sEMG adjustments. The sEMG device (Noraxon USA, Inc., Scottsdale, AZ, USA) was used to measure the activation levels of the TA and MGC. The common-mode rejection ratio was greater than 80 dB and the input impedance was greater than 10 MΩ. The sampling rate for the sEMG data was 1000 Hz. Bipolar Ag/AgCl surface electrodes were placed at an interelectrode distance (center to center) of 2 cm. The electrode was 1 cm in width.

The electrode sites on the body were prepared by shaving the hair, abrading the skin with fine sandpaper, and cleaning the surface with 70% isopropyl alcohol to minimize skin impedance. Electrode placement was determined according to the SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) criteria (23). A licensed physical therapist who was trained and experienced placed the fine-wire sEMG electrodes in accordance with a standardized protocol. The investigator placed the first sEMG electrode to measure the healthy TA and the second to measure the TA on the affected side due to protruded LDH. The electrodes were placed 1/3 proximal to the line formed by the proximal tip of the fibula and the medial malleolus for the TA. The researcher placed the third and fourth electrodes on healthy MGC muscles and MGC muscles affected by protruded LDH, respectively. The last two electrodes were placed on the most prominent bulge of both MGC muscles.

Determination of Maximum Voluntary Isometric Contraction (MVIC): For MVIC testing of the TA muscle, the researcher positioned the participant's ankle joint in dorsiflexion and inversion without extension of the big toe. The researcher then applied resistance to the dorsomedial surface of the foot in the direction of plantar flexion of the participant's ankle joint and eversion of the foot. The participants exerted maximum effort during the MVIC test. They performed 1 trial to understand the procedure. After that they performed 3 repetitions of 5-second duration. During the MVIC determination, the subjects received standardized verbal encouragement to produce maximum effort. A 2-minute rest was given between measurements.

Determination of MVIC% of TA and MGC. The ratio of TA and MGC values that emerged during the activities to the MVIC values of these muscles was called MVIC%. The MVIC% values of the TA and MGC were matched and muscle reciprocal activation values were TA: MGC ("MVIC%" TA / "MVIC%" MGC). During the activities, the MVIC% values of both muscles were measured separately when performing and not performing the AHM.

Activities

Activities performed without the abdominal hollowing maneuver. The researchers showed the patients how to perform the walking, tandem walking, and stair climbing activities. The participants performed all activities three times without the AHM. For the walking activity, the participants took a total of eight steps without deviating from their normal gait pattern. For the tandem walking activity, the participants covered the eight-step distance by performing heel-to-toe walking. For the stair climbing activity, the participants climbed a total of four steps without support from their upper extremities. The researchers visually checked the postures of the participants during all stages of the activities.

Activities performed with the abdominal hollowing maneuver. AHM was taught to the participants in three stages. Participants performed AHM training in both supine and standing positions. In the first stage, the correct breathing pattern for diaphragm activation was demonstrated. In the second stage, the participants applied the movement of pulling the lower abdominal wall slightly towards the spine. Researchers used a pressure biofeedback device for participants who had difficulty learning movement. In the final stage, the patients were taught how to contract the pelvic floor muscle. The training continued until the participants were able to continue the AHM they learned in three stages for 40 seconds. Then, they performed walking, tandem walking, and stair climbing activities with AHM.

sEMG Signal Processing

Noraxon MyoResearch XP Master Edition software (Noraxon, Scottsdale, AZ, USA) was used for the sEMG data processing. The sEMG signals were band-pass filtered (20–450 Hz) and smoothened using the root mean square with a 20-millisecond time window. The peak sEMG activity was measured during 5 s of walking, tandem walking, and stair climbing activities. Next, the internal consistencies between the three repeats determined using the sEMG signals were analyzed by statistical methods (**Figure 1**).

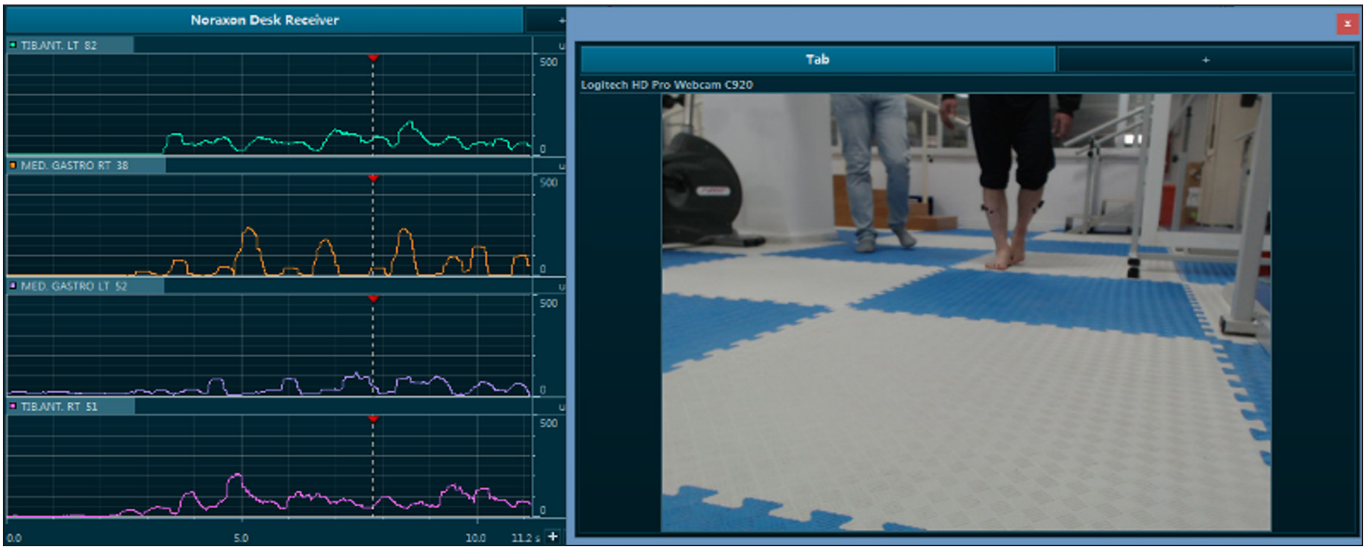

Figure 1. sEMG data recorded during tandem walking activity

Statistical Analysis

The statistical analysis was performed using IBM SPSS Statistics v.28.0.1.1. (IBM, USA). All data were expressed as means and standard deviations for the descriptive data. The intraclass correlation coefficients (ICC3,1) and standard errors of measurement for the mmHg FS error value for the three replicates were used to determine the consistency between trials. The ICCs were classified as poor (< 0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (≥0.90) (24). The standard error of measurement (SEM) was calculated using the SEM formula (25). The paired samples t-test was used for time-dependent measurements to measure the effect of AHM on reciprocal activation, whereas the independent samples t-test was used for independent comparison of mean change differences.

RESULTS

Reliability values ranged from 0.87 to 0.99 with an SEM of 2.22 to 11.98 (**Table 1**). The ICC3,1 was considered "good" or "excellent" for all muscle sEMG measurements. The reliability of the measurements (ICC3,1) was considered "excellent" for healthy TA muscle sEMG measurements during walking (without-AHM: .94, with AHM: .92), tandem walking (without-AHM: .94, with AHM: .95), and stair climbing (without-AHM: .94, with AHM: .97) activities, both without and with AHM. Reliability for the TA muscle on the affected side ranged from good to excellent during walking (without-AHM: .88, with AHM: .92), tandem walking (without-AHM: .91, with AHM: .96), and stair climbing (without-AHM: .92, with AHM: .92), activities. The reliability of sEMG measurements of the MGC muscle on the healthy side was good or excellent for walking (without-AHM: .88, with AHM: .97), tandem walking (without-AHM: .88, with AHM: .92), and stair climbing (without-AHM: .88, with AHM: .92) activities. Similarly, the reliability of measurements taken from the MGC muscle on the affected side was good or excellent during walking (without-AHM: .99, with AHM: .97), tandem walking (without-AHM: .87, with AHM: .96), and stair climbing (without-AHM: .99, with AHM: .99) activities (**Table 1**).

During the tandem walking activity performed with the AHM, the reciprocal activation rates of TA: MGC on the affected and healthy legs converged (p=0.010, d=0.71). However, TA: MGC reciprocal activation rates did not differ between the affected and healthy extremities in the walking (p=0.519, d=0.16) or stair climbing (p=0.180, d=0.35) activities performed with the AHM (**Table 2**, **Figure 2**). When the effect of AHM on the coactivation rates of healthy extremities during activities was examined, a change was observed during tandem walking activity (p=0.016, d=0.65), but no significant coactivation change was observed in walking (p=0.202, d=-0.32) and stair climbing (p=0.469, d=0.18). In the affected extremity, it was observed that AHM did not change the coactivation rate of TA and MGC during any activity (p>0.05).

Table 1. The mean percentage of maximum voluntary isometric contraction values. The intra-class correlation coefficient (ICC3,1), 95% confidence intervals (95%CI), and standard error of measurement (SEM) indicate reliability

%MVIC	Healthy Leg (n=17)			Affected Leg (n=17)		
	MeanSD	ICC3,1 (95%CI)	SEM	Mean±SD	ICC3,1 (95%CI)	SEM
Walking						
TA						
Non-AHM	34.2514.72	0.94 (0.83-0.99)	3.57	35.65±18.23	0.88 (0.70-0.97)	4.42
AHM	28.10±9.18	0.92 (0.78-0.98)	2.22	34.18±15.31	0.92 (0.82-0.97)	3.71
MGC						
Non-AHM	52.8119.35	0.88 (0.70-0.96)	4.69	68.70±40.98	0.99 (0.98-0.99)	9.93
AHM	44.19÷18.46	0.97 (0.92-0.99)	4.47	53.85±16.91	0.97 (0.91-0.99)	4.10
Tandem Walking						
TA						
Non-AHM	50.01±23.58	0.94 (0.82-0.99)	5.72	46.88±21.96	0.96 (0.89-0.99)	5.32
AHM	37.9015.12	0.95 (0.87-0.98)	3.66	40.53±12.31	0.91 (0.80-0.97)	7.60
MGC						
Non-AHM	42.12±16.37	0.95 (0.83-0.99)	3.97	54.16±34.72	0.87 (0.62-0.97)	8.42
AHM	47.2519.70	0.95 (0.88-0.98)	2.98	54.74±31.33	0.96 (0.90-0.99)	4.77
Stair Climbing						
TA						
Non-AHM	38.65±15.59	0.94 (0.87-0.98)	3.78	39.19±17.59	0.92 (0.83-0.97)	4.26
AHM	39.19±14.36	0.97 (0.91-0.99)	3.48	43.07±17.98	0.92 (0.82-0.97)	4.36
MGC						
Non-AHM	68.93±20.94	0.91 (0.78-0.97)	5.07	79.97±49.43	0.99 (0.97-0.99)	11.98
AHM	73.86±21.12	0.96 (0.89-0.99)	5.12	77.24±34.97	0.99 (0.98-0.99)	8.48

Abbreviations: %MVIC: percentage of maximum voluntary isometric contraction, TA: Tibialis anterior, MGC: Medial gastrocnemius, AHM: Abdominal hollowing maneuver, ICC: Intraclass correlation coefficient, SEM: Standard error of measurements, SD: Standard deviation.

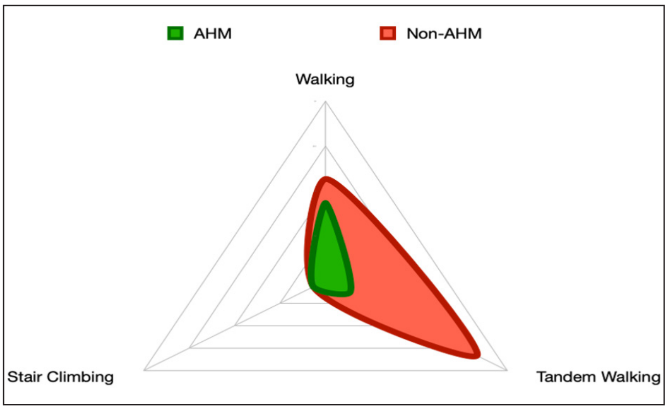

Figure 2. Mean differences in reciprocal activation (TA:MGC) ratios with and without AHM between both lower extremities during walking, tandem walking, and stair climbing activities.

Table 2. Reciprocal activation changes during activities due to the abdominal hollowing maneuver in healthy and affected legs.

Reciprocal Activation Ratio %MVIC (TA/MGC)	Non-AHM Mean±SD	AHM Mean ±SD	p	Effect size (d)
Walking				
Healthy Leg (n=17)	0.71±0.42	0.77±0.51	0.202	-0.32
Affected Leg (n=17)	0.54±0.19	0.64±0.22	0.111	-0.41
Mean Difference (Δ)	0.17±0.46	0.13±0.40	0.519	0.16
Tandem Walking				
Healthy Leg (n=17)	1.25±0.58	0.95±0.38	0.016*	0.65
Affected Leg (n=17)	1.00±0.49	0.99±0.42	0.851	0.04
Mean Difference (Δ)	0.25±0.42	0.04±0.49	0.010**	0.71
Stair Climbing				
Healthy Leg (n=17)	0.58±0.32	0.58±0.32	0.469	0.18
Affected Side (n=17)	0.56±0.31	0.60±0.30	0.191	-0.33
Mean Difference (Δ)	0.02±0.29	0.02±0.29	0.180	0.35

Abbreviations: %MVIC: percentage of maximum voluntary isometric contraction, TA: Tibialis anterior, MGC: Medial gastrocnemius, AHM: Abdominal hollowing maneuver, *paired samples t-test, *independent samples t-test.

DISCUSSION

The purpose of the present study was to examine the effect of the AHM on TA/MGC reciprocal activation and to observe whether there were changes in TA/MGC reciprocal activation during some activities performed. The results showed that, similar to the healthy leg, the AHM, when performed during tandem walking, regulates the reciprocal activation ratio of the TA: MGC affected by L4-L5 disc protrusion. While the extremity activation rates converged with the AHM during tandem walking, no similar activation changes were observed during walking or stair climbing. It is known that the reciprocal activation rates of agonist and antagonist muscles are more precisely adjusted to maintain the balance of the center of mass, especially during low-load tasks (26). It has been reported that while the TA plays a proprioceptive role in wide-stance activities such as walking, it contributes to body stabilization in narrow-stance activities such as tandem walking (27). According to the results of our study, the differences in the reciprocal activation rates between the healthy and affected legs are greater in the activity of the TA to contribute to body stabilization. On the other hand, it is aimed to improve performance and regulate motor behaviors with TrA activation. In order to increase the cortical neuroplastic changes that occur after the AHM performed for this purpose, it is necessary to integrate functional tasks into motor learning stages (28).

The first stage of lumbar stabilization exercises performed on the basis of motor learning is the conscious contraction in the TrA activation (29). Considering that multiple repetitions and sensory feedback are required to increase the quality of contraction, it appears that even the initial AHM performed by LDH patients regulates the lower extremity motor activities somewhat (30). However, in our study, the most dramatic convergence between reciprocal activations of both extremities was seen in tandem walking. On the basis of motor learning, the cognitive and autonomous phases of movement should be performed by integrating various tasks into TrA activation in subsequent phases. According to the results of the present study, tandem walking may be the most appropriate option for tasks to be applied in the advanced stages of spinal stabilization exercises for patients with L4-L5 disc protrusion in which the TA is affected.

Although AHM was frequently used to provide low back and lower extremity motor control in previous studies, the ABM was also heavily preferred. (14, 17, 31, 32). Kim and Kim stated that ABM and AHM increase motor control by changing the rotation angles of the lower extremities in the side lying position and that ABM is more effective than AHM (14). One of the reasons why the ABM applied with functional activities is more effective than the AHM is thought to be that the ABM works more abdominal muscles than the AHM (33). The performance of the abdominal muscles is important to avoid unnecessary rotation of the lumbopelvic muscle. The external and internal oblique muscles, in particular, are important in controlling rotational force. However, intra-abdominal pressure increases significantly during ABM, and this maneuver may not be suitable for patients with LDH. The AHM selected in our study selectively contracts the TrA muscle (12). It has been suggested that the TrA muscle acts to control the translation and rotation of the lumbar spine. Even though AHM using only TrA isn't as good as ABM at giving motor control of the lower extremities, LDH patients may prefer it because it doesn't raise intra-abdominal pressure (17).

Finally, although the effectiveness of motor learning-based structured exercise programs for LDH patients with disc protrusion has been demonstrated in several studies (34-36), studies examining the effectiveness of the AHM integrated into the task from baseline without any exercise program being established are insufficient.

The results of our study showed that rapid integration of the AHM alone into tasks without a multistage designed exercise program can regulate the reciprocal activation rate in the lower extremities. However, as shown in our study, regulation of lower extremity reciprocal activation was only possible with tandem walking. Therefore, selection of the appropriate activity is also important when rapidly integrating the AHM into activities.

There were some limitations of the present study. The first is that the participants were enrolled in the study without a detailed sensory or pain examination. In addition, the results showed the benefit of integrating the AHM into activities in the early period, but 8-week AHM training was not conducted in order to compare these results. Therefore, another limitation of our study was that the TrA muscle, which is expected to be trained for at least 8 weeks, was trained only for 45 minutes and was not compared with a TrA muscle trained for 8 weeks.

CONCLUSION

Our study showed that the AHM, when done during tandem walking, regulates the reciprocal activation ratio of TA:MGC affected by L4-L5 radiculopathy in the similar way as a healthy leg. While the extremity activation rates converged with the AHM during tandem walking, no similar activation changes were observed during walking or stair climbing. In some activities, such as tandem walking, there are differences in reciprocal activation rates between the healthy extremity and the affected extremity due to L4-L5 unilateral radiculopathy caused by LDH. The present study showed that the integration of the AHM into tandem walking brought the reciprocal activation rates of both legs closer to each other and enabled them to exhibit similar behaviors, even without adherence to any exercise protocol. Therefore, tandem walking can be selected as an appropriate activity to combine spinal stabilization exercises performed by L4-L5 LDH patients using the AHM with the task. In addition to these results, it is still unclear to what extent the reciprocal activation rates in the lower extremities will change as a result of longer training of the AHM. In future studies, it will be useful to examine the effect of long-term motor learning-based training of AHM on daily living activities.

ETHICAL DECLARATIONS

Ethics Committee Approval: The study was carried out with the permission of Çankırı Karatekin University Faculty of Health Sciences Ethics Ethics Committee (Date: 09.11.2021, Decision No: 23)

Informed Consent: All patients signed the free and informed consent form.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

Acknowledgment: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors thank Russell Fraser for the English editing service.

REFERENCES

1. Pourahmadi MR, Taghipour M, Takamjani IE, Sanjari MA, Mohseni-Bandpei MA, Keshtkar AA. Motor control exercise for symptomatic lumbar disc herniation: protocol for a systematic review and meta-analysis. BMJ Open 2016; 6: e012426.
2. Özsoy G, İlçin N. The impact of non-specific low back pain on postural control, balance, fall, mobility and physical activity in elderly individuals: a comparative study. Turk J Physiother Rehabil 2021; 32: 67-73.
3. Paoloni M, Di Sante L, Cacchio A, et al. Intramuscular oxygen-ozone therapy in the treatment of acute back pain with lumbar disc herniation: a multicenter, randomized, double-blind, clinical trial of active and simulated lumbar paravertebral injection. Spine (Phila Pa 1976) 2009; 34: 1337-44.
4. Lee JH, Choi KH, Kang S, et al. Nonsurgical treatments for patients with radicular pain from lumbosacral disc herniation. Spine J 2019; 19: 1478-89.
5. Bakhtiary AH, Safavi-Farokhi Z, Rezasoltani A. Lumbar stabilizing exercises improve activities of daily living in patients with lumbar disc herniation. J Back Musculoskelet Rehabil 2005; 18: 55-60.
6. Prasad KS, Gregson BA, Hargreaves G, Byrnes T, Winburn P, Mendelow AD. Inversion therapy in patients with pure single level lumbar discogenic disease: a pilot randomized trial. Disabil Rehabil 2012; 34: 1473-80.
7. López-Díaz JV, Arias-Buría JL, Lopez-Gordo E, Lopez Gordo S, Oyarzún AP. Effectiveness of continuous vertebral resonant oscillation using the POLD method in the treatment of lumbar disc hernia. A randomized controlled pilot study. Man Ther 2015; 20: 481-6.
8. Sherry E, Kitchener P, Smart R. A prospective randomized controlled study of VAX-D and TENS for the treatment of chronic low back pain. Neurol Res 2001; 23: 780-4.
9. Unlu Z, Tasci S, Tarhan S, Pabuscu Y, Islak S. Comparison of 3 physical therapy modalities for acute pain in lumbar disc herniation measured by clinical evaluation and magnetic resonance imaging. J Manipulative Physiol Ther 2008; 31: 191-8.
10. Moon HJ, Choi KH, Kim DH, et al. Effect of lumbar stabilization and dynamic lumbar strengthening exercises in patients with chronic low back pain. Ann Rehabil Med 2013; 37 :110-7.
11. Kahlaee AH, Ghamkhar L, Arab AM. Effect of the abdominal hollowing and bracing maneuvers on activity pattern of the lumbopelvic muscles during prone hip extension in subjects with or without chronic low back pain: a preliminary study. J Manipulative Physiol Ther 2017; 40: 106-17.

12. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine (Phila Pa 1976) 1996; 21: 2640-50.
13. Sánchez-Zuriaga D, López-Pascual J, Garrido-Jaén D, García-Mas MA. A comparison of lumbopelvic motion patterns and erector spinae behavior between asymptomatic subjects and patients with recurrent low back pain during pain-free periods. J Manipulative Physiol Ther 2015; 38: 130-7.
14. Kim DW, Kim TH. Effects of abdominal hollowing and abdominal bracing during side-lying hip abduction on the lateral rotation and muscle activity of the pelvis. J Exerc Rehabil 2018; 14: 226-30.
15. Jung E, Sung J, Uh I, Oh J. The effects of abdominal hollowing and bracing on abdominal muscle thicknesses and pelvic rotation during active straight leg raise. Isokinet Exerc Sci 2022; 30: 1-6.
16. Jull GA, Richardson CA. Motor control problems in patients with spinal pain: a new direction for therapeutic exercise. J Manipulative Physiol Ther 2000; 23: 115-7.
17. Lee W-h. Effects of the abdominal hollowing and abdominal bracing maneuvers on the pelvic rotation angle during leg movement. J Musculoskelet Sci Technol 2020; 4: 70-5.
18. Harput G, Calık M, Erdem MM, Cigercioglu N, Gunduz S, Cınar N. The effects of enhanced abdominal activation on quadriceps muscle activity levels during selected unilateral lower extremity exercises. Hum Mov Sci 2020; 70: 102597.
19. Park D, Lee M, Chung Y. Effect of the abdominal bracing maneuver on muscle activity of the trunk and legs during walking in healthy adults. Phys Ther Rehabil Sci 2022; 11: 119-26.
20. Ennis K, Sizer PS, Sargent E, et al. Abdominal bracing changes lower quarter muscle activity but not reach distances during active forward reach on an unstable surface. Bodyw Mov Ther 2021; 28: 391-6.
21. Faul F, Erdfelder E, Lang A-G, Buchner A. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007; 39: 175-91.
22. Nelson-Wong E, Callaghan JP. Changes in muscle activation patterns and subjective low back pain ratings during prolonged standing in response to an exercise intervention. J Electromyogr Kinesiol 2010; 20: 1125-33.
23. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol 2000; 10: 361-74.
24. Lahey MA, Downey RG, Saal FE. Intraclass correlations: There's more there than meets the eye. Psychol Bull 1983; 93: 586-95.
25. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J Strength Cond Res 2005; 19: 231-40.
26. Bussey MD, Kennedy JE, Kennedy G. Gluteus medius coactivation response in field hockey players with and without low back pain. Phys Ther Sport 2016; 17: 24-9.
27. Lemos T, Imbiriba LA, Vargas CD, Vieira TM. Modulation of tibialis anterior muscle activity changes with upright stance width. J Electromyogr Kinesiol 2015; 25: 168-74.
28. Boudreau SA, Farina D, Falla D. The role of motor learning and neuroplasticity in designing rehabilitation approaches for musculoskeletal pain disorders. Man Ther 2010; 15: 410-4.
29. França FR, Burke TN, Hanada ES, Marques AP. Segmental stabilization and muscular strengthening in chronic low back pain: a comparative study. Clinics (Sao Paulo) 2010; 65: 1013-7.
30. Hauggaard A, Persson AL. Specific spinal stabilisation exercises in patients with low back pain – a systematic review. Phys Ther Rev 2007; 12: 233-48.
31. Vera-Garcia FJ, Elvira JL, Brown SH, McGill SM. Effects of abdominal stabilization maneuvers on the control of spine motion and stability against sudden trunk perturbations. J Electromyogr Kinesiol 2007; 17: 556-67.
32. Grenier SG, McGill SM. Quantification of lumbar stability by using 2 different abdominal activation strategies. Arch Phys Med Rehabil 2007; 88: 54-62.
33. Liebenson C, Karpowicz AM, Brown SH, Howarth SJ, McGill SM. The active straight leg raise test and lumbar spine stability. PM R 2009; 1: 530-5.
34. Searle A, Spink M, Ho A, Chuter V. Exercise interventions for the treatment of chronic low back pain: a systematic review and meta-analysis of randomised controlled trials. Clin Rehabil 2015; 29: 1155-67.
35. França FR, Burke TN, Caffaro RR, Ramos LA, Marques AP. Effects of muscular stretching and segmental stabilization on functional disability and pain in patients with chronic low back pain: a randomized, controlled trial. J Manipulative Physiol Ther 2012; 35: 279-85.
36. França FJR, Callegari B, Ramos LAV, et al. Motor control training compared with transcutaneous electrical nerve stimulation in patients with disc herniation with associated radiculopathy: a randomized controlled trial. Am J Phys Med Rehabil 2019; 98: 207-14.