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The effect of a selected exercise protocol on trunk and lower limb muscle activity of older adults with both low back pain and pronated feet during walking

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Abstract

Background: Low back pain is a common musculoskeletal condition that can impact a person's ability to walk and move comfortably. Pronated foot posture has been suggested as a potential contributor to low back pain, and this study examines its impact on muscle activity during gait in individuals with low back pain.

Aim: This study aimed to investigate whether pronated foot alters the activity timing of trunk and lower limb muscles during gait in low back pain patients.

Materials and Methods: The sample of this study included 32 men with low back pain and pronated foot. Participants were divided into control (n=15, with foot pronated only) and experimental (n=17, with both low back pain and foot pronated) groups. The experimental group did resistance training with Thera-band for 12 weeks, 3 sessions per week. A wireless electromyography system with 9 pairs of bipolar surface electrodes was used to record the electromyography activity timing of back and lower limb muscles (sample rate: 2000 Hz). Two-way ANOVA was used for statistical analysis.

Results: Significant between-group differences were found at baseline onset of EMG activity timing for gastrocnemious medialis ($P<0.001$), gluteus medius ($P<0.001$) and erector spinae at 3rd lumbar vertebral level ($P=0.001$) muscles. Results indicated significant main effects of "Time" for erector spinae at 3rd lumbar vertebral level offset ($P=0.023$), significant main effects of "group" for tibialis anterior offset ($P= 0.039$) and for erector spinae at 3rd lumbar vertebral level offset ($P= 0.010$).

Conclusion: The selected training program changed the timing of erector spinae at 3rd lumbar vertebral level in older adults with both low back pain and pronated feet during walking.

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1. Introduction

Low back pain (LBP) is among the most common health problems seen in primary care [1]. Because of its frequency and its mostly benign character, LBP is often seen as a trivial problem compared to other afflictions that generate a higher mortality risk, like cancer or infectious diseases [2]. The first episode of LBP occurs between 20 and 40 years of age [3], and the prevalence is high at ages from 35 to 55 years old [4]. LBP is among the four most commonly reported symptoms in the elderly [5]. It has been reported that up to 84% of older adults suffer from LBP [6]. Despite its high incidence, there is no clear consensus on its etiology.

One possible cause leading to LBP is abnormal foot function [7, 8]. Abnormal foot pronation, which is pronation occurring in an excessive way, causes increased tibia and femur internal rotation [8, 9], anterior inclination of the pelvis [8, 10], and therefore increases mechanical forces on the lumbar spine [8, 11]. This increases tension on the muscles of this region and rotation of the lumbar vertebrae during gait [12]. Therefore, pronated foot (PF), in association with other factors, should be taken into account when evaluating imbalances in the LBP patients with PF [13].

Pronated foot along with LBP may develop from a lack of muscle strength and stability or from overuse. To quantitatively evaluate the effects of LBP along with PF on lower extremity biomechanics, existing studies have principally focused on three measurement techniques: electromyography (EMG), kinematics, and kinetics. With regard to kinetics, LBP along with PF is associated with increased vertical reaction forces and loading rate, impulse in posterior-anterior reaction force, and positive peak free moments during walking [14]. Also, LBP along with PF is associated with decreased ankle plantar flexion moment, hip flexion moment, and peak positive ankle power during walking [15]. Concerning kinematics, LBP with PF is associated with a decreased peak ankle inversion, peak knee flexion, internal rotation, and peak hip internal rotation [15]. Concerning EMG, LBP along with PF is associated with higher activity of gastrocnemius medialis, gluteus medius, erector spinae and internal oblique muscles during stance phase of walking [15]. Different treatments are often recommended to control excessive PF and LBP [15]. However, their biomechanical mechanism of action on LBP patients with PF is still not fully clear.

Various treatment programs, such as rest, medications, exercise therapy, traction, osteopathic treatment, manipulation, massage, and electrotherapy (e.g., diathermy, laser, musculocutaneous and nerve electrical stimulation, and interferential currents) have been suggested for patients with LBP [16]. Among them, exercise protocols have received more attention within the past 2 decades [16, 17]. This program is commonly used for its short- and long-term advantages, including pain reduction and facilitation of the neuromuscular control at lumbar spine [16, 18].

van Tulder et al. (2000) reported a significant effect of exercise therapy on chronic LBP [19]. Recently, exercises that are related to the engagement of stabilizing muscles such as transverse abdominis (TrA), lumbar multifidus (MF), and internal oblique (IO) have received more attention [16]. These muscles provide segmental stabilization by maintaining a neutral intervertebral position during exercises and functional activities unlike erector spinae and rectus abdominis (which seem to be involved in movement production) [16]. Co-contraction of deep muscles such as TrA, lumbar MF, and IO as well as pelvic floor muscles produce a force that may contribute to the stability of the spine through thoracolumbar fascia and interabdominal pressure mechanisms [16].

Accordingly, these muscles play a supportive role for the spine. For example, lumbar MF muscle resists the force coming from outside by engagement during the full range of spine movement and also during movements of upper and lower extremities. Because these muscles are always active during daily activities, they do not provide much power. However, good endurance and coordination are required to keep the back in normal position through their constant activities (they don't furnish a whole lot power, in spite of the fact that desirable perseverance and coordination are essential to preserve the back in expected function via their constant activities) [16, 20]. Specific exercises that activate abdominal and/or back extensor muscles are advocated to reduce pain and disability [21]. It is claimed that there is a link between local muscle dysfunction and low back pain, with the development of clinical instability in which there is an excessive range of abnormal segmental movement without muscular control [22]. A trunk stabilization training program reduced low back pain in pain developers, but only corrected gluteus medius co-contraction in males [23, 24].

Although, several studies have investigated the effect of exercises on reducing pain and/or improving muscle function in patients with LBP, the effect of exercise on electromyography of the lower limb and trunk muscles in the LBP patients with PF is very scarce in the literature. Therefore, the aim of this study is to investigate the effect of a special training program (reinforcing ankle anti-pronators, knee and hip external rotators, and abdominal muscles) on timing of muscle activity of the lower limb and trunk muscles in the LBP patients with PF during walking.

2. Methods

2.1. Participants

In this experiment study, 15 male older adults with PF only (age: 26.0 ± 2.9 years; height: 174.5 ± 5.5 cm; mass: 78.7 ± 9.9 kg; body mass index: 25.9 ± 3.2 kg/m^2) formed the control group and 17 other male older adults with both LBP and PF formed the experimental group (age: 25.3 ± 2.7 years; height: 173.8 ± 4.9 cm; mass: 79.4 ± 10.0 kg; body mass index: 26.3 ± 3.0 kg/m^2). Participants were recruited from a local clinic. All subjects were right foot dominant as determined by kicking ball test.

An orthopedic surgeon in the local clinic assessed all subjects prior to selection. For any of both the control and experimental groups, subjects required a navicular drop of more than 10mm, and a foot posture index of greater than 10 [25]. Navicular drop was measured as the difference .n navicular height between non-weight bearing and full weight bearing conditions of the foot in standing position [26]. Additional inclusion criteria were a LBP index of>30 based on visual analog pain scale, and a disability index of>10 based on Roland-Morris disability questionnaire [27].

For all groups, the exclusion criteria were a history of major musculoskeletal surgery at trunk and/or lower limbs, neuromuscular disorders, orthopedic related diseases or postural disorders (except feet pronation for experimental groups, and LBP for PF+LBP), limb length discrepancies of greater than 5 mm, and if heavy physical tasks or exercises leading to fatigue were performed in the previous two days prior to the experimentation. The research protocol was approved by the ethical committee of Medical Sciences University of Ardabil (IR-ARUMS-REC-1397-031). All subjects gave their informed consent to participate in the study.

2.2. Apparatus

A portable EMG system (BIO SYSTEM, UK) with nine pairs of bipolar pre-gelled Ag/AgCl surface electrodes (circular in shape with 11 mm in diameter; 25 mm center-to-center distance; input impedance of 100 MΩ; and common mode rejection ratio of>110 dB at 50–60 Hz) was used to record the activity of the tibialis anterior (TA), gastrocnemious medialis (Gas-M), long head of biceps femoris (BF), vastus lateralis (VL), gluteus medius (Glut-M), erector spinae at 3rd lumbar vertebral level (ES_{L3}), rectus abdominus (RA), external oblique (EO), and internal oblique (IO) muscles of the right side at a sampling frequency of 2000 Hz.

Skin surface over the selected muscles was shaved, cleaned with alcohol (70% Ethanol–C_2H_5OH) and abraded gently, according to the SENIAM recommendations prior to the electrodes placement [28].

The electrodes' location for TA, Gas-M, BF, VL, and Glut-M muscles was determined based on the recommendation by SENIAM [8, 28]. For ES_{L3} muscle electrodes were placed vertically on the skin, 3 cm lateral to the related spinous process [8, 28, 29, 30]. For the RA muscle, electrodes were placed 3 cm from the midline of the abdomen and 2 cm above the umbilicus [8, 31]. The electrodes for IO muscle were placed 2 cm inward and distal to the anterior superior iliac spine oriented toward umbilicus at an angle of 45° [15].

2.3. Task, procedure, and data processing

Subjects had five minutes for warm up exercises including walking. During both pre- and post-test, the starting point was set appropriately so that the subject had at least eight steps before entering the calibrated space and stepped on the force plate with his right foot. Three successful barefoot walking trials were analyzed during both pre- and post-test. A trial was considered successful if the foot was landed in the middle of the force plate, all markers were visible, and the EMG signals of all muscles were recorded correctly. EMG signals were processed as described in Farahpour et al. (2018) [15].

2.4. Corrective Exercise Intervention

Elastic resistance bands (Thera-Band®, Akron, Ohio, US) ranging from very low to very high resistance (yellow, red, green, blue, black and silver) were used in this intervention. The 1 m long elastic bands were stretched to twice their resting length prior to each exercise [32, 33]. Following the pre-test, the experimental group performed resistance band exercises for both legs three times per week for eight weeks (i.e., 24 strength training sessions). The participants were familiarized with the exercises prior to training. Each exercise session consisted of a general warm-up (10 min), followed by a resistance training session (35-40 min) and was completed with a cool-down routine. Following an adaptation phase of two weeks using low external resistance (yellow TheraBand®, unless the participant was obviously unchallenged, 1 set of 14 repetitions per exercise [34, 35]), exercise intensity was progressively increased by adapting the resistance of the elastic band (based on the Thera-Band® force elongation table [35] from yellow to red, and further to black). In addition, the exercise volume was extended by increasing the number of sets from one to two. The rate of progression was based on individual improvements (band colour was changed if participants were able to perform 16 repetitions or more in the second set) and reported that they were below seven on the OMNI resistance for active muscle scale (0 extremely easy to 10 extremely hard [36]). The movement velocity during exercises was very low.

The intervention in the experimental group was conducted individually in a physiotherapy clinic, with every session being supervised by a physiotherapist to ensure the correct technique or to modify the exercise or the progression to suit the participants' needs. After the intervention, participants of the experimental group were re-evaluated following the same procedure as the first evaluation. The re-evaluation was scheduled six days after the final intervention session to guarantee that acute physiological responses to training did not interfere with the measurements [8, 37]. The control group did not perform any exercise and was re-evaluated after 8 weeks. All participants were asked not to participate in any other forms of sports or exercise during the intervention period.

2.5. Statistical analysis

The normality of the distribution for outcome measures was confirmed by the Shapiro-Wilk test. Independent t tests were used to analyze any significant differences on the timing of selected muscles between two groups. Statistical within-and between-group differences were assessed by a mixed ANOVA (Time×Group). The effect sizes (Cohen's d) were computed as a ratio of the mean difference divided by the pooled standard deviation. Statistical significance was set at p<0.05. Data were analyzed using the SPSS version 28 software (SPSS Inc., Chicago, IL). All values are reported as mean (standard deviation).

Table 1. Corrective exercise program used in this research

Movement	Description
Hip abductor strength training	Four exercises: in the side-lying position with limb to be strengthened on top; in the standing position; side-stepping with elastic resistance in the distal region of the thigh [38], and the exercise was performed seated on massage table adjusted to position the hip at 60° (from this position, the participant was instructed to activate the hip abductors while keeping the knee at about 90°)
Invertor strength training	The invertors were strengthened in side-lying position [38].
Abdominal strength training	After a light warm-up, subjects performed 2 sets of 8 repetitions of the abdominal crunch, right/ left oblique crunch, abdominal drawing-in, and abdominal bracing. Subjects were instructed to hold each contraction for 5 sec, and a 2-min rest followed each set [39]
Hamstring strength training	In standing position, their legs up from the back upwards and doing the extension of the hip against resistance [40]
Hip external rotation training	This exercise was performed on the hip external rotation muscles while the subject was sitting on a table with a 90° flexion angle [40]

3. Results

The between-group differences on age,. height, mass, and body mass index were not significant .*P*>0.05). The difference. between the navicular drop of PF (12.15 ± 1.51 mm) and PF+LBP (12.24 ± 1.54 mm) groups was also not significant .*P*>0.05).

Significant between-group differences

were found at the baseline onset of EMG activity for Gas-M (*P*<0.001), Glut-M (*P*<0.001) and ES_{L3} (*P*<0.001) muscles (Table 2).

Table 3 describes pre-and post-data for the onset and offset of EMG activity in the trunk and lower limb muscles. The statistical analyses indicated significant main effects of “Time” for ES_{L3} offset (*P*= 0.023; d=0.873) muscle. The statistical analysis indicated significant main effects of “group” for TA offset (*P*= 0.039; d= 0.773) and for ES_{L3} offset (*P*= 0.010; d= 1.000) muscles.

Table 2. Group-specific baseline values of reported timing of selected muscles electromyography amplitude

Muscles	Timing	CG	EG	***P*-value**
TA	Onset	-271.5±177.4	-300.9±192.9	0.659
	Offset	225.1±69.0	256.3±73.3	0.226
Gas-M	Onset	364.2±83.9	213.1±101.2	<0.001*
	Offset	659.5±74.1	657.1±67.9	0.926
BF	Onset	-146.2±28.6	-129.9±31.8	0.139
	Offset	282.2±76.45	245.1±81.2	0.196
VL	Onset	-105.6±86.2	-65.1±46.8	0.104
	Offset	360.1±84.5	424.0±178.9	0.201
Glut-M	Onset	-87.2±58.8	18.0±66.7	<0.001*
	Offset	510.4±117.6	515.9±121.6	0.897
ES_{L3}	Onset	-237.0±238.4	21.6±98.2	0.001*
	Offset	104.1±250.5	202.9±50.8	0.154

Note: CG = control group; EG = experimental group; TA = tibialis anterior; Gas-M = gastrocnemious medialis; BF = biceps femoris; VL = vastus lateralis; Glut-M = gluteus medius; ES_{L3} = erector spinae at 3rd lumbar vertebral level.

*Significant level *P*<0.05

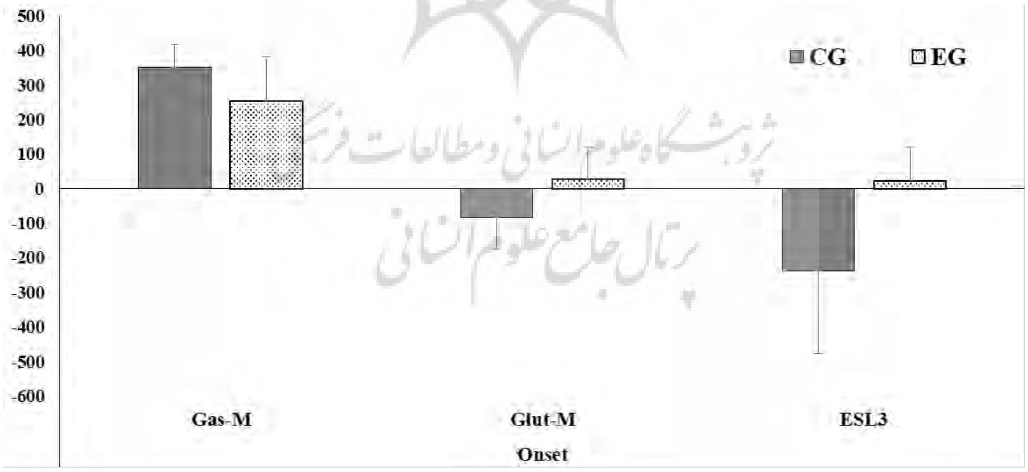

Figure 1. Effects of selected exercises on timing amplitude for trunk and lower limb muscles activity during walking

Table 3. Selected exercises effects on timing amplitude of trunk and lower limb muscles activity during walking

Muscles	Timing	CG (n=15)					EG (n=17)					*p*-value (Partial Eta Square)		
		Pre-test		Post-test		Δ (%)	Pre-test		Post-test		Δ (%)	Main effect: Time	Main effect: Group	Interaction: Time×Group
		M	SD	M	SD		M	SD	M	SD				
TA	Onset	-271.5	177.4	-251.4	197.4	-7.4	-300.9	192.9	-280.5	201.9	-6.7	0.367 (0.02)	0.654 (0.00)	0.995 (0.00)
	Offset	225.1	69.0	188.4	55.8	16.3-	256.3	73.3	245.9	91.3	-4	0.161 (0.06)	*0.039 (0.13)	0.429 (0.02)
Gas-M	Offset	659.5	74.1	646.7	62.3	-1.94	657.1	67.9	652.1	128.4	-0.76	0.559 (0.01)	0.956 (0.00)	0.798 (0.00)
BF	Onset	-146.2	28.6	-146.7	37.4	0.3	-129.9	31.83	-130.0	75.39	769.8	0.978 (0.00)	0.239 (0.04)	0.985 (0.00)
	Offset	282.2	76.2	260.5	89.6	-7.6	245.1	81.2	264.5	54.7	7.9	0.932 (0.00)	0.481 (0.01)	0.147 (0.06)
VL	Onset	-105.6	86.2	-79.3	41.9	-24.9	-65.1	46.8	-43.8	91.6	-32.7	0.060 (0.11)	0.091 (0.09)	0.841 (0.00)
	Offset	360.1	84.5	338.8	97.9	-5.9	424.0	178.9	408.2	144.7	-3.7	0.388 (0.02)	0.128 (0.07)	0.897 (0.00)
Glut-M	Offset	510.4	117.6	522.1	109.6	2.29	515.9	121.6	521.3	134.6	1.04	0.689 (0.00)	0.950 (0.00)	0.882 (0.00)
ES$_{L3}$	Offset	104.1	250.5	8.4	185.9	-91.9	202.9	50.8	183.8	57.5	-9.41	0.023* (0.16)	*0.010 (0.20)	0.121 (0.07)

Note: CG = control group; EG = experimental group; TA = tibialis anterior; Gas-M = gastrocnemious medialis; BF = biceps femoris; VL = vastus lateralis; Glut-M = gluteus medius; ES$_{L3}$ = erector spinae at 3rd lumbar vertebral level; M = mean; SD = standard deviation.

*Significant level *P*<0.05, 2-w ANOVA

4. Discussion

The aim of this study was to investigate the effect of a special training program (reinforcing ankle anti-pronators, knee and hip external rotators, and abdominal muscles) on timing of muscle activity of the lower limb and trunk muscles in the LBP patients with PF during walking.

In this study, significant between-group differences were found at baseline onset of EMG activity for Gas-M, Glut-M and ES_{L3} muscles. In describing pre and post data for onset and offset of EMG activity in trunk and lower limb muscles, the statistical analyses showed significant main effects of “Time” for ES_{L3} offset muscle. Also, the statistical analysis indicated significant main effects of “group” for TA offset (*P*= 0.039; d= 0.773) and for ES_{L3} offset (*P*= 0.010; d= 1.000) muscles.

An increased activity of the ES_{L3} [15, 41, 42] and hamstring [15, 43] muscles was reported in LBP patients. Besides, in LBP patients with PF, higher activity of Gas-M, Glut-M, ES_{L3}, and IO muscles compared with healthy controls was reported [15]. In the early stance phase, TA acts to decelerate the ankle plantar flexion allowing a smooth flat foot phase [15, 44].

In the loading response phase, the onset time of BF and ES_{L3} muscles in experimental group during post-test was significantly sooner than during pre-test. Also, in the loading response phase, the onset time of TA, Gas-M, VL and Glut-M muscles in experimental group during post-test was significantly later than during pre-test. In the loading response phase, the offset time of TA, Gas-M, VL and ES_{L3} muscles in experimental group during post-test was significantly sooner than during pre-test. Also, in the loading response phase, the offset time of BF and Glut-M muscles in experimental group during post-test was significantly later than during pre-test. Some studies have postulated that the higher muscle activity in LBP patients is a neuromuscular response to reduce pain by better lumbopelvic stabilization [15, 41, 45, 46, 47]. However, this higher muscle activity in the lumbopelvic region could be associated with trunk inclination control that normally occurs in walking [48].

Ntousis et al. (2013) reported that pronating or supinating bilaterally or unilaterally a normal foot, did not alter the EMG activity of the RA muscle in a quiet standing position [49]. The statistical analyses yielded significant “Time×Group” Interaction during mid-stance for EO muscle and during push off phase for RA muscle.

Murley et al. (2009) [50], and Hunt, Smith and Torode (2004) [51] also reported higher TA activity in PF individuals compared to healthy control group during walking. In the early stance phase, TA acts to decelerate the ankle plantar flexion. allowing a smooth flat foot phase. [15, 44, 50, 51]. The activity of TA muscle in this phase was not associated with the strong coupling co-activation of tibialis posterior muscle [15, 51]. It appears that the higher TA muscle activity in PF individuals is a neuromuscular adaptation to compensate the PF. Since the higher activity of TA muscle was observed in both PF with and without LBP, it should be excluded as an indication of LBP.

5. Conclusion

The selected training program changed the timing of erector spinae at 3rd lumbar vertebral level in older adults with both low back pain and pronated feet during walking. Since erector spinae muscles play an important role in low back pain and lumbar stability in daily activities, this study’s training program may improve recruiting motor units of erector spinae muscles, resulting in improvement of low back pain and lumbar stability.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

The research was conducted based on the Helsinki Declaration.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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