Effect of foot placement on EMG of trunk muscles during asymmetrical squat lifting in healthy Thai males aged 18-23 years

ผลของตำแหน่งเท้าต่อคลื่นไฟฟ้ากล้ามเนื้อลำตัวขณะยกด้วยท่าสควอทแบบไม่สมมาตร ในชายไทยสุขภาพดีอายุระหว่าง 18-23 ปี

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ABSTRACT

Background: Torso twisting during lifting represents an asymmetrical posture that can result in bodily injuries. Foot positioning while lifting is one of the factors used in posture design to reduce the risk of injuries. However, the impact of foot positioning on the trunk muscle activity in asymmetrical lifting is still uncertain.

Objective: To investigate the effect of foot placement on the electromyographic activity of trunk muscles during asymmetrical squat lifting.

Method: Thirty-one males participated in the study. All participants were asked to lift a 7-kilogram box measuring 36x26x28 centimeters from the floor to a stand at hip level on the right side. Two types of foot placement were investigated: equal foot position (EP) and left forward stride position (LP). Eight electromyography (EMG) of both sides of lumbar erector spinae (ES), multifidus (MF), internal abdominal oblique (IO), and external abdominal oblique (EO) were performed. The percent of MVC of average amplitude EMG of the lifting and twisting phases of the lifting task was analyzed.

Results: The results showed higher activity of IO, ES, and MF during the twisting phase ($p<0.05$), and the right ES worked harder than the left during the twisting phase in both foot positions ($p<0.05$). However, activity of the right IO was greater than left IO during the twisting phase in EP.

Conclusion: The foot position did not affect the EMG of the investigated trunk muscles during asymmetrical lifting. However, IO, ES, and MF showed higher activity in both foot positions during the trunk twist.

Keywords: Asymmetrical lifting, EMG, Foot position, Manual material handling, Trunk muscles

บทคัดย่อ

ที่มาและความสำคัญ: การบิดของลำตัวขณะยกแสดงถึงท่าทางที่ไม่สมมาตรซึ่งส่งผลให้เกิดการบาดเจ็บของร่างกาย ตำแหน่งการวางเท้าขณะยกเป็นปัจจัยหนึ่งที่ใช้ในการออกแบบท่าทางเพื่อลดความเสี่ยงของการบาดเจ็บ อย่างไรก็ตามข้อมูลเกี่ยวกับผลของการวางเท้าต่อการทำงานของกล้ามเนื้อลำตัวขณะยกแบบไม่สมมาตรยังไม่ชัดเจน

วัตถุประสงค์: เพื่อศึกษาผลของตำแหน่งการวางเท้าต่อคลื่นไฟฟ้ากล้ามเนื้อลำตัวขณะยกด้วยท่าสควอทแบบไม่สมมาตร

วิธีการวิจัย: อาสาสมัครเพศชาย 31 คน เข้าร่วมในการศึกษา ทั้งหมดจะทำการยกกล่องหนัก 7 กิโลกรัม ขนาด 36x26x28 เซนติเมตร จากพื้นไปบนแท่นวางระดับเอวทางด้านขวา รูปแบบการวางเท้า 2 แบบได้ถูกนำมาใช้ในการทดสอบ ได้แก่ การวางเท้าเท่ากัน และการวางเท้าเยื้องกัน แปดคลื่นไฟฟ้ากล้ามเนื้อของ

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erector spinae (ES) multifidus (MF) internal abdominal oblique (IO) และ external abdominal oblique (EO) ทั้ง 2 ด้านจะถูกบันทึก ค่าร้อยละการหดตัวสูงสุดของค่าเฉลี่ยคลื่นไฟฟ้ากล้ามเนื้อของช่วงยกและช่วงบิดลำตัวจะถูกนำมาวิเคราะห์

ผลการวิจัย: ผลวิจัยแสดงให้เห็นการทำงานของกล้ามเนื้อ IO ES และ MF มีค่ามากในช่วงการบิดตัว ($p<0.05$) และกล้ามเนื้อ ES ด้านขวาทำงานมากกว่าด้านซ้ายในช่วงการบิดตัวในรูปแบบการวางเท้าทั้งสองแบบ ($p<0.05$) อย่างไรก็ตาม พบการทำงานของกล้ามเนื้อ IO ข้างขวามากกว่าข้างซ้ายเฉพาะช่วงบิดลำตัวเมื่อวางเท้าแบบเท่ากัน

สรุปผล: ตำแหน่งการวางเท้าไม่มีผลต่อคลื่นไฟฟ้ากล้ามเนื้อลำตัวขณะทำการยกแบบไม่สมมาตร อย่างไรก็ตาม การทำงานของกล้ามเนื้อ IO ES และ MF มีการทำงานที่มากทั้ง 2 รูปแบบการวางเท้าขณะที่ลำตัวมีการบิด

คำสำคัญ: การยกแบบไม่สมมาตร คลื่นไฟฟ้ากล้ามเนื้อ ตำแหน่งเท้า การเคลื่อนย้ายวัตถุด้วยมือ กล้ามเนื้อลำตัว

Introduction

Manual material handling (MMH) serves as a technique for relocating objects, finding utility both in day-to-day activities and professional contexts. More than 500,000 workers are reported to experience mobility-related musculoskeletal disorders as a result of MMH, as stated by the National Institute for Occupational Safety and Health (NIOSH)[1,2]. Within the realm of MMH, a variety of techniques are encompassed, such as lifting, lowering, pulling, pushing, and carrying. Notably, lifting objects emerges as the predominant approach for object manipulation. Recent studies have indicated a correlation between lifting objects and bodily injuries impacting joints and muscles. These injuries, predominantly affecting the back, account for over 60% of reported cases[3]. Numerous factors play a role in the occurrence of lifting-related injuries. According to a recent investigation, these injuries stem from various sources, including twisting work (25.8%), handling heavy objects (14.1%), and engaging in repetitive movements (4.4%)[4]. Evidence suggests a significant injury risk associated with asymmetrical lifting, and this specific lifting posture may be difficult to avoid, particularly in occupations that require the relocation of objects from one location to another[5]. Within specific lifting tasks, the introduction of torso twisting during lifting engenders this asymmetrical dynamic. In certain lifting scenarios, it has been observed that lifting necessitates bodily twisting, thereby inducing asymmetry. Prior studies have extensively documented the vulnerability to injuries arising from lifting performed in an asymmetric manner[6,7,8]. Kim and Zhang studied the effects of asymmetrical lifting on spinal load and trunk muscle activities[6]. The findings revealed that in cases of asymmetrical lifting, the spine experienced a heightened lateral shear force, alongside increased muscular activity within the back, as compared to symmetrical lifting. As a result, the heightened shear force and increased muscular activity have the potential to increase the susceptibility to lower back injuries during lifting activities. To ensure safety during lifting and mitigate the risk of injury, a range of recommendations regarding lifting posture are provided. One such recommendation pertains to the positioning of the feet during lifting. Previous research has demonstrated that the placement of the feet during lifting influences both spinal load and muscle functionality[9,10,11]. As a suitable stance for typical lifting, a position with one foot forward has been advocated. According to a study conducted by Kingma and colleagues in 2004, positioning the foot adjacent to the object led to a reduction in spinal moment and pressure when compared to placing the foot behind the object[9]. Most studies indicate that adopting a stance with one foot positioned forward while lifting an object lessens the body's susceptibility to injury. Nevertheless, the current body of research primarily focuses on foot positioning within the context of symmetrical lifting, leaving the impact of foot placement on asymmetric lifting comparatively unexplored. Therefore, the objective of this study was to investigate the effect of foot placement on trunk muscle activity during instances of asymmetrical lifting.

Methods

This study determined the sample size according to the effect size of research by Marras & Mirka and Zhou et al, which utilizes the variables L5/S1 moment and trunk torque exertion for calculations and computes them using the GPower version 3[12,13]. Thirty-one males, right-handed, aged 18–23 years, participated in the study. They were recruited following announcements posted around Thammasat University, Thailand. The research protocol was explained to them, and they were asked to sign an informed consent. This research on human subjects conformed to all relevant national regulations, institutional policies and was in accordance with the tenets of the Helsinki Declaration. It was approved by The Human Research Ethics Committee of Thammasat University (Science), Thailand (COA No.262/2560) and registered with the Thai Clinical Trials Registry (TCTR20171010003). The participants underwent questionnaires for inclusion and exclusion criteria. They were excluded if they reported cardiopulmonary or neurological problems, had a history of back pain, or had surgery in any area in the last six months. All participants completed the Physical Activity Readiness Questionnaire (PAR-Q) and answered “no” to all the PAR-Q questions, which means that they had a low risk of medical complications from exercise and were ready to participate in the study[14].

EMG measurements

Electromyography was used to measure activity of four muscles on both sides. The skin of both sides of the lumbar erector spinae (ES), multifidus (MF), internal abdominal oblique (IO), and external abdominal oblique (EO) area was prepared to decrease the skin impedance below 10 kiloohms by shaving the hair, rubbing the skin, and cleaning with alcohol. Surface EMG electrodes (Ag-AgCl) were applied to the skin over the recorded muscles. The surface EMG electrode placements were attached as follows[15] : the IO site was approximately 2 cm medially and inferiorly to the anterior superior iliac spine. The EO site was located above the IO site 12–15 cm from the umbilicus. The ES site was 5 cm lateral to the L2 spinous process, and the MF site was 3 cm lateral to the L5 spinous process. The EMG signal frequency was 1,000 Hz using an 8-channel wireless system (Noraxon, AZ, USA). The signals were filtered using a 0–1,000 Hz bandpass and processed using a root mean square with a window period of 20 milliseconds.

Testing of maximal voluntary contraction (MVC)

The maximal amplitude of the muscles was recorded during three forceful isometric tests that aimed to normalize the muscle activity. The MVC was then averaged from those three trials. Participants were tested in crook sitting with the hip and knee flexed at 60 degrees, the trunk flexed at 45 degrees, and hands behind the head. They were asked to combine flexion and contralateral rotation while resisting at the shoulder. The EO was tested in flexion with rotation to the opposite side, while IO was flexion with rotation to the same side. Left and right rotations were tested to obtain data for both sides of IO and EO. For ES and MF, participants were asked to do maximum isometric trunk extension in prone position. In all positions, the pelvis and feet were strapped to maintain stability of the body parts. The MVC data were then used to normalize the EMG data into %MVC during the asymmetrical lifting.

Testing protocol

Participants were asked to lift a wooden box of 7 kg weight (recommend weight limit from NIOSH equation), 36x26x28 cm size from the floor to a stand at the hip level on the right. Speed of lifting was controlled by using a metronome at 54 beats/minute. They had to lift five times in each foot position; the equal foot position (EP) and the left foot forward stride position (LP). During EP the feet were equally placed at 5 cm distance behind the box while standing with the feet spread at approximately shoulder width. For LP, the left foot was positioned beside the left side of the box at 5 cm distance and the right foot remained behind the box with the feet spread at approximately shoulder width (Figure 1). Prior to commencing the testing, participants underwent a 10-minute familiarization training session. Participants were asked to lift the box from the floor and to place it on the stand at the hip level of the right side, approximately 60 degrees to the frontal plane. Lifting phase and twisting phase of the lifting were then analyzed (Figure 2). The lifting phase started as the box was lifted off the ground until the body was fully extended, and the twisting phase, which involved torso rotation, followed the lifting phase until the box was placed onto the table. The testing order for the ten trials (5 times in the EP position and 5 times in the LP position) was randomized using software-generated orders. To prevent muscle fatigue, participants rested for two minutes between a lift and five minutes between foot positions. The Borg CR10 was used to screen fatigue during the test.

Raw electromyographic activity was recorded from the point at which the box was lifted off the ground until it was placed on the table. The lifting phase and the twisting phase were then subjected to analysis. Signal processing through the rectify and average method was applied to the raw electromyographic (EMG) activity of eight muscles in each phase. The data was normalized as a percentage of maximal voluntary contraction (%MVC) and subjected to statistical analysis.

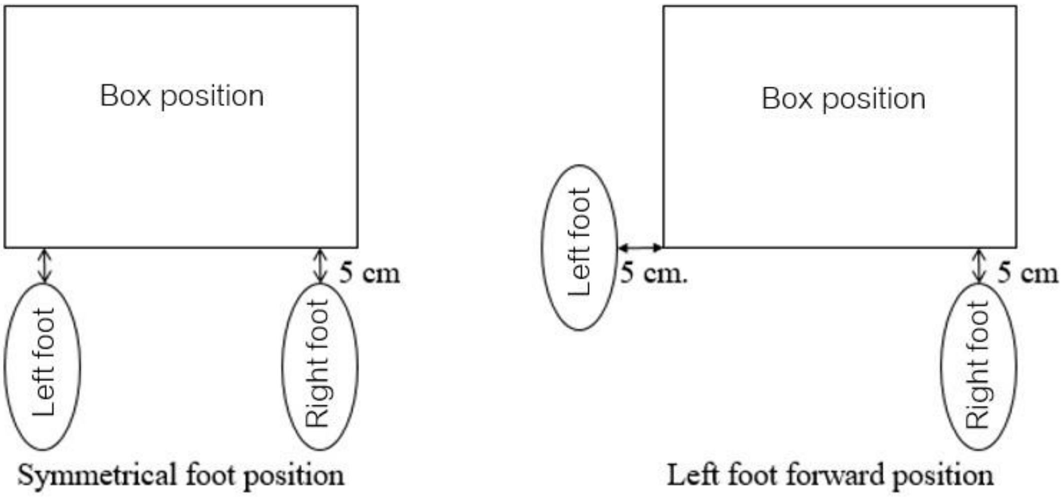

Figure 1 The position of the foot during asymmetrical lifting.

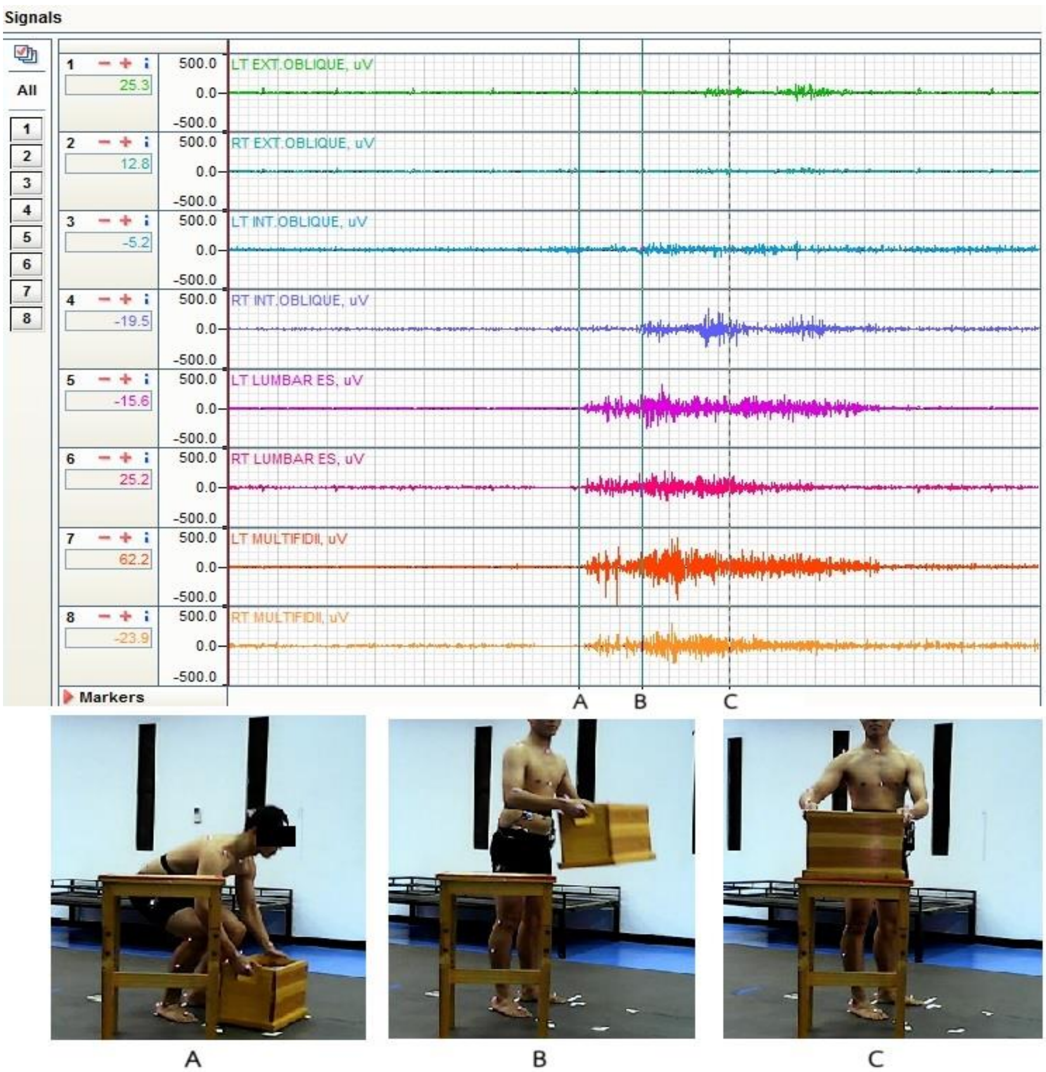

Figure 2 Raw EMG of 2 phases of the asymmetrical lifting. The lifting phase (A->B) and twisting phase (B->C).

Data analysis

The statistical analysis was performed using SPSS for Windows version 22. A p-value of less than 0.05 was considered statistically significant. Normal distribution of the data was analyzed using the Shapiro-Wilk test. Homogeneity of variance among the variables was evaluated using Levene's test and then further analyzed by three-way ANOVA (phase, side, foot position) with pairwise comparison using the Bonferroni test.

Results

The demographics of the participants are shown in Table 1. All participants underwent the lifting task with two different foot positions. The Borg CR10 was used to screen body fatigue and showed 0.19±0.33 within a range of 0–1 before the lifting task and 0.74±0.56 within a range of 0–2 after the lifting task. This indicated that the lifting task had a negligible effect on fatigue of the participants.

Table 1 Demographic data of the participants (N=31)

Characteristics	Mean±SD	Range
Age (years)	20.68±0.94	18–23
Weight (kg)	64.48±8.81	47–79
Height (cm)	175.19±6.06	162–185
BMI (kg/cm^2)	20.94±2.21	17.65–24.11

Data of all variables were found to be normally distributed and population variances were considered equal. The main and interaction effects, muscle side (left, right), lifting phase (lifting, twisting), and foot position (EP, LP) of all muscles are shown in Table 2. All muscles showed only a statistically significant difference in phase as the main effect ($p<0.05$) and only ES showed a significant difference in sides ($p<0.05$). For the interaction effect, only IO was found to have significant interaction between phase and side ($p<0.05$).

The result of pairwise comparison of the main variables by using the Bonferroni test is shown in Table 3. The EMG activity of the left and the right side of ES and MF was significantly higher during the twisting phase in both foot positions when compared to the lifting phase ($p<0.05$). Moreover, EMG activity on the right side of ES was significantly higher when compared to the left side in the twisting phase in both foot positions ($p<0.05$). Furthermore, only in EP was the EMG activity of the right IO greater than the left IO ($p<0.05$) during the twisting phase. The study showed no difference in EMG activity when comparing foot positions in the lifting or twisting phase ($p>0.05$).

Discussion

The abdominal muscles

The results for both sides of the EO muscles revealed that they were only activated 5–6% throughout the asymmetrical lifting and were not affected by the phase of the lifting nor the foot positions. This low activation of the muscles was comparable to Lee's work in 2002 and Salehi Sahl Abadi's work in 2018[12,16]. In the latter work, the MVC of EO was about 10–30% for lifting a small object from floor to knuckle height, and it was even lower, at about 10% if the lifting speed was increased[16].

Table 2 The p-value for the main and interaction effect of phase, side, and foot position of asymmetrical lifting task (n=31).

Variables		%MVC							
		EO		IO		ES		MF	
<u>Main effect</u>		Mean±SD	*p-value**	Mean±SD	*p-value**	Mean±SD	*p-value**	Mean±SD	*p-value**
Phase	Lifting	5.26±3.18	0.039**	12.15±7.76	<0.001**	21.25±9.22	<0.001**	23.75±8.60	<0.001**
	Twisting	5.95±4.35		14.82±10.00		35.25±10.36		38.36±10.27	
Side	Left	5.51±2.76	0.560	13.05±9.49	0.189	27.05±11.13	0.006**	30.52±11.99	0.205
	Right	5.70±2.76		13.92±8.57		29.67±12.92		31.59±11.94	
Foot position	EP	5.67±4.18	0.712	13.96±10.07	0.153	29.01±12.24	0.168	31.63±12.24	0.169
	LP	5.54±3.43		13.01±7.87		27.70±11.55		30.48±11.69	
Interaction effect									
Phase*Side		0.354		0.015**		0.094		0.723	
Phase*Foot position		0.308		0.052		0.485		0.196	
Side*Foot position		0.559		0.984		0.893		0.482	
Phase*Side*Foot position		0.794		0.618		0.783		0.600	

<u>Abbreviation:</u> EO, external abdominal oblique; IO, internal abdominal oblique; ES, erector spinae; MF, multifidus; EP, equality foot position; LP, left forward stride position.

*Data were analyzed by the three-way repeated measures ANOVA, **significant level *p-value* <0.05

Table 3 Pairwise comparison of the main variables in percent maximal voluntary contraction (%MVC) of the asymmetrical lifting task (n=31).

	%MVC of foot positions									
		Lifting phase				Twisting phase			Between phases (*p*-value)	
Muscles	Side	EP	LP	*p*-value*	Side	EP	LP	*p*-value*	EP	LP
EO	Left	4.85±2.39	5.18±2.52	*0.626*	Left	6.09±3.16	5.91±2.84	*0.785*	*0.061*	*0.263*
	Right	5.46±3.81	5.57±3.81	*0.869*	Right	6.26±6.34	5.52±4.35	*0.657*	*0.225*	*0.987*
p-value*		*0.360*	*0.553*			*0.802*	*0.552*			
IO	Left	12.50±8.86	12.53±8.38	*0.983*	Left	14.52±11.63	12.62±9.04	*0.150*	*0.129*	*0.946*
	Right	11.44±6.95	12.11±6.98	*0.617*	Right	17.36±11.52	14.77±6.96	*0.052*	*<0.01***	*0.046***
p-value*		*0.424*	*0.748*			*0.033***	*0.107*			
ES	Left	20.86±10.14	20.60±8.43	*0.891*	Left	34.41±9.67	32.32±8.56	*0.268*	*<0.01***	*<0.01***
	Right	22.28±9.83	21.25±8.74	*0.584*	Right	38.49±11.13	36.66±11.27	*0.333*	*<0.01***	*<0.01***
p-value*		*0.451*	*0.731*			*0.032***	*0.022***			
MF	Left	23.48±8.70	23.26±9.50	*0.896*	Left	39.31±10.43	36.05±9.89	*0.052*	*<0.01***	*<0.01***
	Right	24.09±8.39	24.17±8.16	*0.961*	Right	39.65±10.22	38.44±10.63	*0.470*	*<0.01***	*<0.01***
p-value*		*0.713*	*0.584*			*0.842*	*0.155*			

Abbreviation: EO, external abdominal oblique; IO, internal abdominal oblique; ES, erector spinae; MF, multifidus; EP, equality foot position; LP, left foot forward stride position. *Data were analyzed by the three-way ANOVA with pairwise comparison using the Bonferroni test, **Significant level *p-value* <0.05

Regarding the IO muscle, the phase of the lifting and the side of the muscle had an effect on the %MVC of the muscle and it was found to be activated around 12% during asymmetrical lifting. Increased activity was observed on the right side of IO during the twisting phase, especially in EP. This was due to the assigned right turn during the twisting phase of the lift. This result is similar to the research conducted by Marras et al, which found that the IO and EO muscles exhibit increased activity during twisting motions[17]. Therefore, the IO muscle might help during the trunk turning according to its anatomical function with co-contraction to create additional intra-abdominal pressure during the lifting. In 2014, Kawabata studied the association of abdominal pressure during lifting and found that increasing abdominal pressure was related to the lifting load during dynamic lifting ($r = 0.94–0.97$)[18]. Marras and Mirka studied EMG of trunk muscles and intra-abdominal pressure when angular trunk acceleration and trunk twists were varied during lifting exertions and observed that acceleration and asymmetry of the lifting might affect the activity of trunk muscles[12]. Coactivation of muscles was observed, and the oblique muscle groups increased their activity as the trunk acceleration increased. It was concluded that the oblique muscles had an important role while the trunk became asymmetrical. Therefore, intra-abdominal pressure was minimally changed during the task[9,11]. This might indicate that the increase in co-contraction might not mean to increase but to preserve the intra-abdominal pressure during asymmetrical lifting. Lamberg and Hagins investigated breath control during manual freestyle lifting and found that participants increased the inspired volume before the lift-off of the load and modulated the sum of the inspired volume in relation to the magnitude of the load[19]. The IO muscle helps to preserve the spine's stability. Panjabi stated that the spine's stability depends on its morphology and the correct functioning of the stabilizing muscles[20].

<u>The back muscles</u>

The ES and MF muscles were activated by 20% during lifting and showed no difference in EMG activity during the lifting phase (considered symmetrical lifting) similar to the results of previous studies[7,9,12,21,22]. However, we found increased activation (40%) of ES and MF during the twisting phase, especially on the right ES. Therefore, the right longissimus and iliocostalis function as extensor and might also serve as trunk rotator[22,23]. The longissimus originates at lumbar spinous and transverse processes, sacrum, iliac crest, and lumbosacral aponeurosis and inserts at transverse processes of T1–T12 and ribs 9–10. At the same time, iliocostalis originates at medial and lateral sacral crests, medial iliac crest, and inserts at angles of ribs 6–12. These two muscles have some of the muscle fibers arranged in the oblique that might help in lateral flexion or rotation of the spine during asymmetrical lifting.

Consistent with the work of Danneels in 2001, there was no significant difference between left and right MF in the lifting and twisting phase[8]. This might be because MF is a stabilizer that needs co-contraction and conjoins with IO to preserve spine stability during lifting. The MF might also act as during extension and be anticipated in the torque production during the lifting phase.

The effect of foot position on muscle activity

In this study the foot position did not affect muscle activity as recorded by EMG. This can be explained by the minor difference in the base of support between EP and LP. Due to ethics, only lightweight objects were used in the study to minimize the risk of injury to the participants. The activation patterns of the muscles might have been more distinct with heavier objects.

Recommendation

During lifting people should not twist the trunk to place the box since the ipsilateral muscle on the side of turning works a lot leading to muscle injury.

Limitations

The study only investigated asymmetrical lifting with turning to the right and included only young, right-handed males. Results might have been different with left-handed participants and/or with turning to the left. In addition, age, gender, training status might affect muscle activity. Other factors are the weight of the object, lifting speed, and the turning angle during the twisting phase. These latter three factors were controlled in the study but different values for weight, speed, or angle might have led to different results. Furthermore, the object's weight was only 7 kg and the lifting was only repeated five times per position to minimize the risk of injury for the participants. In this research, only trunk muscle work was investigated. Extending the work by analysis of the activity of other muscles of trunk and to muscles of the extremities, possibly also measuring spinal load could help to better estimate the risk of injury. Moreover, prospective investigations into the effects of trunk length and the angle of trunk torsion are areas of potential interest.

Conclusion

The foot position did not affect the EMG of the investigated trunk muscles during asymmetrical lifting. However, IO, ES, and MF showed higher activity in both foot positions during the trunk twist. The right ES showed the highest activity.

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Conflicts of interest

All authors state no conflict of interest.

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