EFFECTS OF GENDER AND RECURRENT LOW BACK PAIN ON LIFTING STYLE

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Abstract. **Objective:** The purpose of this study was to examine the influence of gender and existing, recurrent low back pain (rLBP) on lower extremity and trunk mechanics, as well as neuromuscular control, during a lift task. **Design:** A multivariate design was used to examine the effects of gender and group on biomechanical and neuromuscular control variables in randomized symmetric and asymmetric lifting. **Methods:** 68 Males and females with rLBP and healthy performed symmetric and asymmetric weighted box lifting trials to a 1 meter height table. **Results:** Lifting style was different between gender and between the rLBP versus healthy groups during a 1m box lifting. A significant two-way interaction effect between gender and group was observed for multifidus muscle activity and knee rotation in asymmetric lifting. Several gender and group main effects were observed in pelvis obliquity, trunk flexion and side flexion, knee abduction angles in symmetric lifting; and in pelvis obliquity and rotation, trunk flexion and side flexion, hip abduction, knee abduction angles, external oblique and internal oblique muscles activity in asymmetric lifting. **Conclusions:** Females and individuals with rLBP appear to use different lifting styles that emphasize movement at the pelvis accompanied by poor kinematic control features at the hip, trunk and knee. Clinicians should be mindful of these changes when developing prevention and rehabilitation programs aimed at improving trunk control in preparation for lifting tasks during domestic and occupational activities.

Key words: low back pain, lifting, clinical biomechanics, injury prevention

Introduction

Lifting is a major activity in daily life, where individuals are required to manually manage materials and loads throughout occupational tasks and activities of daily living. Individuals are required to manage those materials while perform tasks in restricted areas as they negotiate different body positions (Gallagher et al. 2011; Ulrey and Fathallah 2013). Such lifting behaviors are used in a repeated fashion during various occupational engagements, such as healthcare (Karahan et al. 2009; Theilmeier at al. 2010), farm animal management (Pal at al. 2010), labor employment (Ropponen et al. 2012) and performing arts (Alderson et al. 2009).

Individuals typically sustain a slouched posture during a lift sequence that is accentuated when returning to upright position with the load (Maduri et al. 2008). Such a pattern appears to increase the compressive forces between the lumbar vertebrae (Arjmand et al. 2009). Moreover, the shear forces on the lumbar spine region are increased when lifting from that slouched position. Lumbar spinal segments in individuals without lower back pain (LBP) appear to be tolerant of a 700 N versus 1000 N shear force during repetitive versus occasional shear exposures, respectively (Gallagher and Marras 2012). However, repeated lifting in a slouched posture appears to increase those shear forces during manually demanding activities, especially when the individual has a history of LBP (Pal et al. 2010). Such repeated loading places the individual at a higher risk for injuries to the lumbar spine and lower extremity, in part because the lower extremities share similar neuromuscular control- specifically anterolateral aspects of the leg, medial foot, and toe region (Schafer 2012).

Low back pain is reported in 75–80% of the population and can significantly influence an individual's quality of life (Martin et al. 2009). Low back pain is the second can lead to cause for missed days at work, potentially leading to disability and major socioeconomic consequences (Hayden et al. 2012). Low back pain can result from mechanical irritations of selected anatomical structures, such as the intervertebral disc (Manchikanti at al. 2009a; Manchikanti et al. 2009b; Wolfer et al. 2008), zygapophyseal joint (Datta at al. 2009; Manchukonda et al. 2007) and lumbar spinal nerve root (Konnai et al. 2000). While low back pain can develop in response to various pathological conditions, such as degenerative arthritis (Goode et al. 2013; Igarashi et al. 2004) or intervertebral disc disease (Gawri et al. 2014; Saleem et al. 2013), it commonly results from abrupt or repetitive mechanical stressors, such as heavy lifting, a fall or prolonged periods of sitting or standing *(*Handout on Health: Back Pain... 2013). The majority of individuals with LBP experience the condition on a recurrent basis, suggesting that once individuals experience an acute LBP episode it is more likely that they will experience further episodes (Stanton et al. 2010). Symptoms of recurrent low back pain (rLBP) can range from muscle ache to shooting or stabbing pains, which can limit flexibility and/or range of motion (Handout on Health: Back Pain... 2013). As a result of limitations in flexibility and range of motion, rLBP can alter an individual's overall functional capacity and ultimately heighten the risk for additional lower extremity injury (Haddas et al. 2014). Moreover, the onset and persistence of rLBP is complex, compounded by many risk factors that are personal (age, smoking habits, weight), psychosocial (stress, social support), and physical (lifting, twisting, compression) in nature (Handout on Health: Back Pain... 2013).

Lifting performance appears to be influenced by gender Gross and Battie (2005). examined the association between maximum amount of weight lifted during the floor-to-waist lift and various clinical and psychosocial factors. They found that women demonstrated lower maximum weight during five consecutive lifts versus male counterparts. Smeets et al. (2007) compared male and female subjects with non-specific LBP in the number of fully completed floor to waist-test lifting cycles during a progressively increasing lift task. They discovered that female subjects performed fewer lifting cycles versus male subjects. The authors concluded that this decrease was disproportionate to the females' lower body mass. Similarly, Reneman et al. (2007) found that males out performed females during a high-intensity lifting task. The female subjects demonstrated significantly lower maximal weight that was lifted five times within 90 seconds. In addition, the females' observed level of lifting intensity was not significantly different from the males' score, based on the Borg CR-10 scale.

The female's differences in lifting response, coupled with their disproportionate decrease in lifting performance when compared to male counterparts, implies increased vulnerability to injury and subsequent clinical consequences. Such a disparity places the female at greater risk for injury and resulting rLBP, which is reinforced by their reduced functional capacity across various tasks (Chenot et al. 2008; Takala and Viikari-Juntura 2000). Because employees in such occupational endeavors are exposed to intense, repetitive lifting encounters, such findings support the connection between gender, lifting response, and injury. Moreover, the presence of existing rLBP symptoms may complicate the gender differences and the resulting female's vulnerability. However, data that describe the underlying mechanisms responsible for such differences are limited. The purpose of this study was to examine the influence of gender and existing, rLBP on lower extremity and trunk mechanics, as well as neuromuscular control, during a 1m box-lift task. Such findings will help elucidate the underlying mechanisms that contribute to the connection between gender, lifting response and the risk for developing and sustaining rLBP.

Methods

Experimental Approach to the Problem

A multivariate design was used to examine the effects of gender and group (healthy versus rLBP) on biomechanical and neuromuscular control variables in symmetric (forward) and asymmetric (right and left) lifting.

Subjects

Thirty-seven healthy individuals (20 males and 17 females) and thirty-one rLBP individuals (16 males and 15 females) participated in the study (Table 1). All subjects were between the ages of 18 and 35 years. Volunteers were excluded if they had a history of knee pain, surgery to the knee or lumbar spine, active abdominal or gastrointestinal conditions, or pregnancy (all documented by self-report). All participants read and signed an informed consent form approved by Texas Tech University review board.

Table 1. Subjects anthropometrics data

	Healthy		rLBP	
	Males (N = 20)	Females (N = 17)	Males (N = 16)	Females (N = 15)
Age (years)	19.6 ±4.22	21.29 ±4.22	22.31 ±1.80	20.87 ±2.53
Mass (kg)	77.25 ±12.20	58.81 ±7.21	84.27 ± 10.77	65.63 ±9.75
Height (m)	1.77 ±0.09	1.65 ±0.05	1.81 ±0.09	1.70 ±0.05
Box mass (kg)	17.12 ±3.89	9.20 ±2.51	16.30 ±4.54	9.82 ±2.97
Same day pain*	0.13 ±0.57	0.00 ±0.00	0.8 3 ±0.75	1.12 ±1.03
Last week average pain*	0.12 ±0.36	0.03 ±0.11	2.62 ±1.51	3.15 ±1.52
Last week worst pain*	0.62 ±1.61	0.01 ±0.02	4.21 ±1.71	5.42 ±2.04

*Visual analog scale from least to worst (1–10).

Procedures

Subjects filled out a visual analog pain scale to indicate if they were experiencing any pain, along with a map defining the pain location (Table 1). Participants were excluded if they had pain that was referred into the lower extremity. The subjects were then taught how to perform the protocol of symmetric and asymmetric lifting. Lifting technique was based on the discretion of the individual and the subject's box weight was determined by their maximum psychophysically acceptable weight (Table 1). Electromyography (EMG) (Delsys Inc. 2000Hz) sensors were then placed on the right side internal oblique (IO), external oblique (EO), erector spinae (ES), and multifidus

(Mf) at the fifth lumbar (L5) spinal level, as well as the rectus femoris(RF), vastus medialis (VM), semitendinosus (ST), gluteus maximus (GMx) and gluteus medius (GMd) all on the subjects right side(Barbero, Merletti, Rainoldi, 2012). Ground reaction forces (GRFs) were collected for each leg (AMTI 2000Hz). The skin was cleaned with alcohol, shaved if necessary, and then lightly abraded to reduce impedance. Subjects then performed maximum voluntary contraction (MVC) tests for all muscles listed above. The MVC outcomes were used later to normalize subjects' muscle activity during the lifting maneuver. Forty-seven reflective markers were then placed on bony landmarks on the trunk and lower extremity in order to calculate joint angle (Figure 1). A static trial was then collected to note marker placement.

Figure 1. Marker set

Participants performed nine weighted box (0.65 m long, 0.35 m wide, 0.15 m high) lifting trials to a 1m height table in forward, right and left side directions (Figure 1). All trials were randomized. Three-dimensional kinematics (VICON Nexus) were collected from the lower extremities and lumbar spine at a sampling rate of 100 Hz.

Data Reduction

Dependent variables included 3D trunk, hip, knee joint angle and EMG linear envelop magnitude for lower extremity and trunk muscles. Kinematics and linear envelop variables were analyzed at two times-0.05s after lifting was initiated and again 0.05s before the subject placed the box on the table. All raw data were exported from the Vicon Nexus system and imported into a custom Matlab program (Mathworks Inc., v7.10.0, Natick, MA) and Visual3D for processing.

Statistical Analyses

All dependent variables were assessed for distribution normality using the Shapiro-Wilk test. A multivariate design was used to examine the effects of gender and group on biomechanical and neuromuscular control variables in symmetric (forward) and asymmetric (right and left) lifting.

A MANOVA was used to determine the effect of gender (males versus females) and group (Healthy versus rLBP) for each dependent variable. The alpha level was initially set to 0.05 but corrections were made within each statistical family using the Holm-Sidak correction for the multiple dependent variables,(Glantz, 2011) resulting in an initial alpha level of 0.008 for the kinematic variables and 0.012 for the EMG variables, based on the number of dependent variables within each family. Follow-up tests were conducted as necessary, with alpha correction at each step. Statistical analyses were conducted using SPSS, Version 21.0 (IBM, Inc., Chicago, IL).

Results

Lifting style was different between gender and between the rLBP versus healthy group during the 1m box lifting. A significant two-way interaction effect between gender and group was observed for Mf muscle activity at the initial position (p = 0.012, η_p^2 = 0.181) in symmetric lifting (Figure 2) and knee rotation angle at final position (p = 0.004, η_p^2 = 0.126) in asymmetric lifting (Figure 3). No other dependent variables exhibited a significant two-way interaction effect. Several significant main effects for group and gender were observed during the 1m lifting maneuver (Tables 2–3).

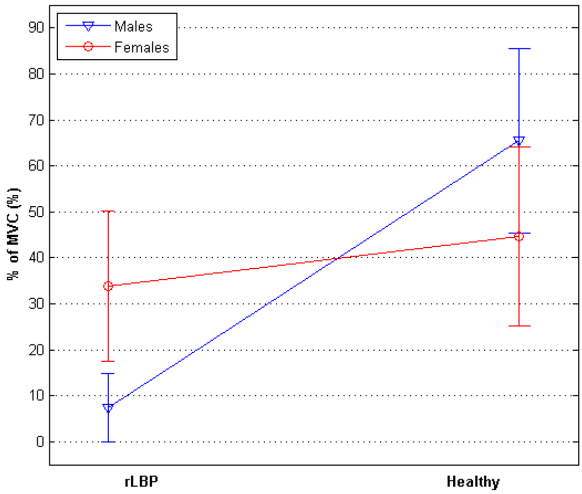

Figure 2. Significant two-way interaction effect between gender and group for Multifidus muscle activity at initial position in symmetric lifting

Several significant group main effects were observed during the 1 m lifting. The rLBP presented a larger pelvis rotation angle at final position (*p* = 0.003, η_p^2 = 0.128), and larger hip abduction angle at final position (p = 0.001,

$\eta_p^2 = 0.093$) in asymmetric lifting when lifting to the right. Furthermore, the rLBP group produced more EO muscle activity at initial position ($p = 0.012$, $\eta_p^2 = 0.183$) (Table 2).

Table 2. Group main effect variables

	Symmetric Lifting				Asymmetric Lifting – Right				Asymmetric Lifting – Left			
	Healthy		rLBP		Healthy		rLBP		Healthy		rLBP	
Variable	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI
1	2	3	4	5	6	7	8	9	10	11	12	13
Pelvis Anterior Tilt Initial	26.60 ±12.18	26.66–30.66	25.15 ±12.01	20.66–29.63	25.90 ±11.86	21.94–29.86	25.90 ±11.86	21.94–29.86	25.84 ±11.76	21.92–29.77	24.05 ±12.60	19.35–28.76
Pelvis Obliquity Initial	1.91 ±3.63	0.70–3.13	1.34 ±4.32	–0.26–2.96	1.74 ±3.07	0.71–2.77	1.78 ±3.76	0.37–3.18	1.83 ±3.43	0.69–2.98	1.11 ±3.84	–0.32–2.55
Pelvis Rotation Initial	–0.70 ±3.25	–1.79–0.37	–0.30 ±3.75	–1.71–1.09	–0.55 ±3.57	–1.73–0.64	–0.15 ±3.68	–1.53–1.21	–0.80 ±3.37	–1.98–0.32	–0.47 ±3.51	–1.78–0.84
Trunk Flexion Initial	35.01 ±12.68	30.78–39.24	31.29 ±12.47	26.63–35.95	35.04 ±13.23	30.62–39.45	32.11 ±11.82	27.69–36.52	34.84 ±12.94	30.52–39.15	31.02 ±13.06	26.14–35.90
Trunk Side Flexion Initial	–1.93 ±4.18	–3.32–(–0.53)	–1.08 ±5.97	–3.31–1.15	–2.76 ±15.60	–4.08–(–1.44)	–2.11 ±5.68	–4.23–0.01	–1.07 ±4.01	–2.41–0.26	–0.08 ±4.64	–1.82–1.64
Trunk Rotation Initial	–1.03 ±4.28	–2.45–0.39	–5.82 ±32.89	–18.11–6.45	–1.24 ±4.56	–2.76–0.27	–6.50 ±32.24	–18.54–5.53	–0.15 ±4.36	–1.60–1.30	–5.20 ±32.84	–17.45–7.06
Hip Flexion Initial	55.82 ±9.95	52–50–59.14	53.88 ±9.78	50.23–57.53	56.64 ±10.81	53.04–60.25	53.73 ±9.91	50.02–57.43	56.40 ±9.85	53.12–59.69	54.92 ±10.14	51.14–58.71
Hip Abduction Initial	42.68 ±17.11	36.98–48.39	35.01 ±23.56	26.20–133.20	40.95 ±18.09	34.91–46.98	38.00 ±20.68	30.27–45.72	38.30 ±20.16	31.58–45.02	36.67 ±22.88	28.12–45.21
Hip Rotation Initial	31.74 ±31.93	11.09–42.39	18.91 ±33.72	–5.12–42.71	43.21 ±25.93	34.57–51.86	14.21 ±28.76	–16.79–43.62	37.23 ±36.21	8.49–45.97	21.29 ±38.57	–0.41–43.16
Knee Flexion Initial	56.50 ±11.13	52.79–60.21	54.39 ±15.01	48.79–60.00	56.76 ±12.43	52.61–60.90	53.27 ±18.57	46.33–60.20	56.64 ±13.66	52.08–61.19	55.54 ±14.71	50.04–61.03
Knee Abduction Initial	–20.27 ±27.84	–30.23–5.68	–32.28 ±25.86	–40.01–(–1.55)	–2.69 ±41.78	–19.97–14.57	–30.97 ±32.04	–34.01–12.06	–18.16 ±38.21	–24.24–7.91	–23.22 ±25.84	–33.95–7.49
Knee Rotation Initial	–6.14 ±45.41	–21.00–9.29	–15.17 ±47.41	–33.17–2.87	–10.38 ±21.46	–21.89–10.88	–15.08 ±19.40	–31.90–6.26	–10.89 ±36.45	–25.40–6.38	–15.78 ±39.46	–23.31–4.25
Pelvis Anterior Tilt Final	9.19 ±5.35	9.18–10.98	11.50 ±5.23	9.54–13.45	7.62 ±28.37	5–84–9.39	9.88 ±3.11	8.72–11.05	8.71 ±5.06	7.02–10.40	9.01 ±3.51	7.70–10.32
Pelvis Obliquity Final	–0.39 ±2.23	–1.13–0.35	0.43 ±1.82	–0.25–1.11	–8.57 ±4.85	–8.57–(–10.19)	–10.40 ±5.01	–12.27–(–8.52)	7.54 ±4.48	6.05–9.04	9.53 ±5.02	7.65–11.41
Pelvis Rotation Final	0.02 ±2.61	–0.85–0.89	–0.07 ±4.06	–1.58–1.44	47.28 ±10.97*	43.63–50.94	54.51 ±8.32	51.40–57.62	–45.75 ±9.57	–48.95–(–42.56)	–51.83 ±11.50	–56.12–(–47.54)
Trunk Flexion Final	0.22 ±10.44	–3.25–3.70	0.87 ±7.83	–2.05–3.79	0.84 ±9.32	–2.26–3.95	–2.26 ±7.67	–5.13–0.59	1.14 ±10.00	–2.19–4.48	1.61 ±8.47	–1.54–4.78
Trunk Side Flexion Final	–0.26 ±3.02	–1.27–0.74	–0.60 ±3.11	–1.76–0.56	–4.35 ±4.55	–2.83–(–5.87)	–5.17 ±4.61	–6.90–(–3.45)	3.30 ±4.72	1.72–4.87	3.27 ±4.97	1.41–5.13
Trunk Rotation Final	–0.07 ±3.24	–1.16–1.00	–6.15 ±32.56	–18.31–6.00	19.58 ±6.62	17.35–21.77	11.36 ±33.61	–1.18–23.92	–20.77 ±6.25	–22.85–18.68	–11.80 ±33.61	–24.35–0.75
Hip Flexion Final	8.74 ±6.30	6.64–10.84	11.73 ±6.98	9.12–14.33	18.32 ±7.60	15.78–20.86	23.17 ±8.21	20.10–26.24	4.02 ±6.58	1.82–6.22	3.80 ±9.33	0.31–7.28
Hip Abduction Final	5.15 ±4.65	3.60–6.71	3.47 ±4.67	1.72–5.21	2.21 ±4.19*	0.81–3.60	–3.09 ±5.00	–4.96–(–1.22)	6.31 ±10.69	2.74–9.87	5.71 ±8.63	2.48–8.93
Hip Rotation Final	13.53 ±10.04	10.18–16.88	16.41 ±14.00	11.18–21.64	2.29 ±10.19	–1.10–5.69	2.67 ±15.81	–3.22–8.58	20.39 ±14.42	15.58–25.20	25.97 ±15.13	20.32–31.62
Knee Flexion Final	1.09 ±5.49	–0.73–2.93	0.52 ±5.53	–1.54–2.58	–3.48 ±5.51	–5.32–(–1.64)	–3.47 ±6.93	–6.06–(–0.88)	12.99 ±7.98	10.32–15.65	13.19 ±8.80	9.90–16.48

1	2	3	4	5	6	7	8	9	10	11	12	13
Knee Abduction Final	1.08 ±2.89	0.11–2.04	3.06 ±6.10	0.79–5.34	2.79 ±2.94	1.80–3.77	5.42 ±7.34	2.67–8.16	0.66 ±14.78	–4.26–5.59	–0.28 ±13.27	–5.24–4.67
Knee Rotation Final	0.44 ±7.59	–2.08–2.97	–2.23 ±12.77	–7.00–2.53	–16.34 ±11.59	–20.20–(–12.47)	–21.63 ±19.68	–28.98–(–14.28)	16.54 ±12.89	12.24–20.84	12.25 ±16.41	6.12–18.39
EO Initial (% of MVC)	17.71 ±38.61	11.80–53.43	6.33 ±10.12	1.45–14.12	1.80 ±2.95	1.86–5.46	3.00 ±4.69	1.92–7.92	12.73 ±16.35*	5.66–19.81	5.00 ±4.00	2.58–7.42
IO Initial (% of MVC)	17.00 ±21.63	3.01–37.01	18.78 ±22.80	1.25–36.31	11.60 ±13.46	5.12–28.32	3.50 ±6.12	2.93–9.93	2.43 ±2.87	0.23–5.09	3.43 ±4.42	0.67–7.53
ES Initial (% of MVC)	23.57 ±32.30	6.31–53.45	20.56 ±29.83	2.38–43.49	36.40 ±31.00	2.10–74.90	4.50 ±7.79	3.68–12.68	16.71 ±15.78	2.11–31.32	22.57 ±30.76	4.38–69.52
Mf Initial (% of MVC)	10.43 ±13.92	2.45–23.31	20.11 ±31.53	4.13–44.35	12.20 ±13.91	5.08–29.48	15.00 ±28.46	4.87–44.87	39.29 ±33.67	8.14–70.43	4.29 ±7.13	2.31–10.88
RF Initial (% of MVC)	8.14 ±7.42	1.28–15.01	9.89 ±14.19	1.02–20.80	7.80 ±6.79	0.64–16.24	2.00 ±4.00	1.20–6.20	24.57 ±25.60	0.89–48.25	13.29 ±26.38	4.11–37.68
VM Initial (% of MVC)	20.29 ±19.02	2.69–37.88	18.44 ±20.65	2.57–34.32	9.60 ±5.59	2.65–16.55	11.83 ±24.83	4.23–37.90	6.43 ±6.05	0.83–12.03	3.14 ±4.74	1.24–7.53
ST Initial (% of MVC)	14.57 ±25.47	8.99–38.13	3.56 ±3.94	0.53–6.58	3.40 ±3.43	0.87–7.67	3.33 ±5.16	2.09–8.75	7.43 ±7.48	0.51–14.35	3.14 ±4.74	1.24–7.53
Gmx Initial (% of MVC)	4.29 ±4.57	0.06–8.51	8.22 ±12.79	1.61–18.06	3.60 ±3.20	0.38–7.58	1.17 ±2.04	0.98–3.31	4.29 ±3.09	1.42–7.15	1.43 ±1.98	0.41–3.27
Gmd Initial (% of MVC)	18.71 ±26.64	5.93–43.36	13.89 ±20.30	1.72–29.50	14.20 ±14.20	3.43–31.83	3.83 ±6.58	1.08–10.74	13.43 ±11.70	2.61–24.25	4.86 ±6.59	1.24–10.96
EO Final (% of MVC)	19.00 ±27.95	6.85–44.85	6.00 ±6.55	0.96–11.04	7.20 ±8.84	3.78–18.18	2.83 ±2.85	1.17–4.82	9.29 ±10.81	0.71–19.29	4.57 ±7.70	2.55–11.69
IO Final (% of MVC)	4.86 ±5.14	1.10–9.62	11.22 ±16.08	1.14–23.59	19.20 ±16.96	1.86–40.26	4.67 ±7.65	3.37–12.70	53.29 ±47.87	9.49–91.60	15.00 ±28.21	4.11–41.10
ES Final (% of MVC)	31.14 ±31.30	2.19–60.10	14.11 ±15.58	2.13–26.09	34.40 ±22.72	6.19–62.61	10.50 ±16.34	6.65–27.65	50.57 ±38.33	13.38–94.52	11.43 ±15.12	2.56–25.41
Mf Final (% of MVC)	8.14 ±7.46	1.28–15.01	9.89 ±14.19	1.02–20.80	23.80 ±15.30	4.80–42.80	17.33 ±27.44	8.44–46.14	33.29 ±22.69	12.30–54.27	16.43 ±25.17	6.85–39.71
RF Final (% of MVC)	6.00 ±9.74	3.01–15.01	1.78 ±2.04	0.20–3.35	10.00 ±13.32	4.54–26.54	0.67 ±1.03	0.42–1.75	7.57 ±11.64	3.20–18.34	1.29 ±1.89	0.46–3.03
VM Final (% of MVC)	7.86 ±14.08	5.17–20.89	5.11 ±6.19	0.35–9.87	10.00 ±12.62	5.68–25.68	7.50 ±13.70	3.89–21.89	9.71 ±10.33	0.15–19.28	8.00 ±12.53	3.64–19.64
ST Final (% of MVC)	8.86 ±8.72	0.79–16.93	7.22 ±8.43	0.74–13.71	8.20 ±7.39	0.98–17.38	5.33 ±9.68	2.83–15.50	8.86 ±6.46	2.88–14.84	6.57 ±9.43	2.15–15.29
Gmx Final (% of MVC)	11.00 ±12.08	0.17–22.17	10.11 ±16.63	2.68–22.90	20.40 ±23.55	8.85–49.65	4.67 ±7.89	2.61–12.95	17.86 ±19.73	0.39–36.11	7.43 ±10.26	2.06–16.92
Gmd Final (% of MVC)	13.00 ±13.39	0.61–25.39	12.11 ±16.12	0.28–24.50	35.00 ±35.87	9.54–79.54	9.33 ±14.45	5.84–24.51	33.43 ±31.70	4.11–62.75	9.43 ±13.20	2.78–21.64

Positive: Flexion, Abduction/Right obliquity/Side Flexion, Right/Internal rotation.
*Significant different.

Several significant gender main effects were observed during the 1m lifting. Females produced a greater pelvis anterior tilt angle at final position ($p = 0.006$, $\eta_p^2 = 0.114$), a reduced trunk flexion angle at initial position ($p = 0.001$, $\eta_p^2 = 0.333$), reduced trunk side flexion angle at final position ($p = 0.002$, $\eta_p^2 = 0.139$) and reduced trunk flexion angle at final position ($p = 0.001$, $\eta_p^2 = 0.202$), accompanied by a greater knee abduction angle at initial ($p = 0.001$, $\eta_p^2 = 0.202$) and final position ($p = 0.004$, $\eta_p^2 = 0.127$) in symmetric lifting (Table 3).

Table 3. Gender main effect variables

	Symmetric Lifting				Asymmetric Lifting – Right				Asymmetric Lifting – Left			
	Males		Females		Males		Females		Males		Females	
Variable	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI	Average ±SD	95% CI
1	2	3	4	5	6	7	8	9	10	11	12	13
Pelvis Anterior Tilt Initial	23.91 ±10.07	20.20–27.32	28.32 ±13.76	23.27–33.37	22.39 ±10.07	18.98–25.80	28.17 ±13.95	23.06–33.29	22.71 ±9.93	19.34–26.07	27.75 ±13.85	22.67–32.84
Pelvis Obliquity Initial	1.81 ±4.28	0.36–3.26	1.48 ±3.55	0.17–2.78	2.07 ±3.33	0.94–3.20	1.39 ±3.44	0.13–2.65	1.96 ±3.21	0.87–3.04	0.99 ±4.02	–0.48–2.47
Pelvis Rotation Initial	–0.73 ±12.40	–1.92–0.45	–0.28 ±3.44	–1.54–0.97	–0.46 ±3.48	–1.64–0.71	–0.26 ±3.78	–1.65–1.11	–0.41 ±3.15	–1.48–0.64	–0.92 ±3.73	–2.29–0.43
Trunk Flexion Initial	40.03 ±6.21*	36.91–43.15	25.58 ±11.66	21.30–29.85	40.88 ±8.28*	38.08–43.68	25.42 ±11.72	21.12–29.72	39.85 ±9.72*	36.55–43.14	25.33 ±12.10	20.89–29.77
Trunk Side Flexion Initial	–2.26 ±5.89	–4.26–(–0.27)	–0.71 ±3.76	–2.09–0.66	–3.21 ±5.47	–5.06–(–1.35)	–1.60 ±3.71	–2.96–(–0.24)	–1.69 ±4.80	–3.31–(–0.06)	0.59 ±3.30	–0.61–1.80
Trunk Rotation Initial	–0.36 ±6.52	–2.24–2.17	–6.82 ±31.71	–18.45–4.80	–0.60 ±6.76	–2.89–1.68	–7.07 ±31.12	–7.07–(–18.49)	0.32 ±6.32	–1.81–2.46	–5.58 ±31.83	–17.26–6.08
Hip Flexion Initial	56.18 ±8.85	53.18–59.17	53.53 ±10.86	49.54–57.51	56.56 ±9.27	53.42–59.69	53.92 ±11.65	49.65–58.20	56.74 ±9.38	53.56–59.92	54.58 ±10.56	50.70–58.46
Hip Abduction Initial	34.88 ±16.69	29.22–40.53	44.33 ±23.39	35.75–52.75	43.10 ±18.41*	26.87–39.33	47.20 ±17.47	40.79–53.61	30.17 ±21.24*	22.98–37.36	46.16 ±18.08	39.53–52.50
Hip Rotation Initial	33.65 ±21.53	26.36–40.93	17.11 ±39.02	–16.45–39.77	29.72 ±35.27	17.78–41.65	30.82 ±36.26	2.84–48.79	24.03 ±34.48	13.04–35.02	25.19 ±26.79	–3.03–43.36
Knee Flexion Initial	57.32 ±12.09	53.23–61.41	53.51 ±13.80	48.45–58.58	55.91 ±12.18	51.78–60.03	54.37 ±18.73	47.49–61.24	56.86 ±13.36	52.33–62.38	55.31 ±14.98	49.82–60.81
Knee Abduction Initial	–7.10 ±12.75*	–21.87–2.34	26.03 ±12.03	12.03–28.13	–18.91 ±19.71*	–32.40–(–3.41)	21.79 ±22.86	10.60–34.19	–2.37 ±12.47*	–17.05–7.07	13.76 ±16.25	6.21–23.74
Knee Rotation Initial	–2.67 ±31.45	–24.65–2.70	–9.81 ±31.79	–28.82–10.81	–12.41 ±26.96	–30.52–4.30	–14.57 ±23.43	–29.57–3.51	–16.14 ±29.44	–30.8–(–3.49)	–7.79 ±25.69	–27.35–4.21
Pelvis Anterior Tilt Final	8.55 ±4.95*	6.87–(12.17)	12.17 ±5.28	10.23–14.11	8.30 ±4.78	6.68–9.92	9.02 ±4.39	7.40–10.63	7.88 ±4.86	6.24–9.53	9.96 ±3.56	8.66–11.27
Pelvis Obliquity Final	0.47 ±2.20	–0.26–1.22	–0.60 ±1.81	–1.26–0.62	–7.29 ±4.57*	–8.84–(–5.74(	–11.82 ±4.32	–13.40–(–10.23)	7.12 ±4.05	5.75–8.49	9.95 ±5.21	8.04–11.86
Pelvis Rotation Final	0.20 ±3.09	–0.83–1.25	–0.28 ±3.58	–1.60–1.03	47.79 ±9.57	44.49–50.97	53.76 ±10.63	49.86–57.66	–45.01 ±9.29*	–48.15–(–41.86)	–52.50 ±11.23	–56.63–(–48.38)
Trunk Flexion Final	3.41 ±8.17*	0.64–6.18	–5.07 ±8.50	–8.19–(–1.95)	3.42 ±8.31*	0.61–6.24	–5.17 ±6.70	–7.63–(–2.70)	4.35 ±8.43*	1.50–7.20	–5.25 ±7.71	–8.08–(–2.42)
Trunk Side Flexion Final	–1.44 ±3.17*	–2.52–(–0.37)	0.78 ±2.42	–0.10–1.67	–6.16 ±5.49*	–7.72–(–4.61)	–3.04 ±3.99	–4.50–(–1.58)	2.32 ±4.57	0.78–3.87	4.40 ±4.89	2.61–6.20
Trunk Rotation Final	–0.18 ±4.69	–1.77–1.39	–5.83 ±31.85	–17.51–5.85	19.12 ±6.78	16.83–21.42	12.14 ±33.18	–0.28–24.31	–19.22 ±6.97	–21.58–(–16.86)	–13.88 ±33.33	–26.11–(–1.66)
Hip Flexion Final	9.41 ±6.52	7.21–11.62	10.85 ±6.99	8.29–13.42	19.38 ±7.68	16.78–21.98	21.78 ±8.69	18.59–24.97	2.93 ±7.26	0.47–5.38	5.08 ±8.49	1.96–8.19
Hip Abduction Final	5.18 ±4.99	3.49–6.87	3.49 ±4.24	1.94–5.05	0.46 ±5.32	–1.33–2.26	–0.89 ±5.17	–2.79–1.00	6.37 ±8.46	3.51–9.23	5.66 ±11.21	1.58–9.77
Hip Rotation Final	16.47 ±10.11	13.05–19.89	12.91 ±13.73	7.87–17.94	2.61 ±11.59	–1.30–6.53	2.29 ±14.47	–3.01–7.60	23.72 ±13.02	19.31–28.13	21.92 ±16.99	15.69–28.15
Knee Flexion Final	–0.09 ±5.92	–2.10–1.90	1.93 ±4.77	0.18–3.68	–4.88 ±6.73	–7.15–(–2.60)	–1.85 ±5.00	–3.69–(–0.2)	13.32 ±7.41	10.81–15.82	12.80 ±9.33	9.38–16.23
Knee Abduction Final	0.50 ±3.14*	–0.55–1.56	3.67 ±5.58	1.62–5.72	3.05 ±3.29	1.93–4.16	5.03 ±7.18	2.39–7.66	–3.39 ±10.00	–6.78–(–0.01)	4.46 ±16.80	–1.70–10.62

1	2	3	4	5	6	7	8	9	10	11	12	13
Knee Rotation	0.49	−2.96–	−2.20	−5.96–	−18.13	−23.97–	−19.38	−24.61–	15.67	11.70–	13.40	6.97–
Final	±10.21	3.94	±10.25	1.56	±17.24	(−12.30)	±14.26	(−14.15)	±11.72	19.64	±17.52	19.82
EO Initial	3.90	0.37–	23.67	9.84–	2.13	0.68–	3.33	1.01–	2.50	0.21–	4.00	1.80–
(% of MVC)	±4.93	7.43	±31.45	67.17	±3.35	4.93	±5.77	13.68	±3.20	4.79	±4.89	11.80
IO Initial	20.90	3.26–	13.17	3.64–	9.13	0.65–	2.00	0.61–	22.70	7.01–	12.00	2.14–
(% of MVC)	±24.66	38.54	±16.01	29.98	±11.69	18.90	±3.46	10.61	±31.53	52.41	±20.19	44.14
ES Initial	18.20	2.22–	28.00	7.51–	23.75	0.77–	6.33	2.92–	27.70	3.94–	7.00	3.41–
(% of MVC)	±28.54	38.62	±33.84	63.51	±29.32	48.27	±10.97	23.58	±33.21	51.46	±9.05	21.41
Mf Initial	7.40	1.51–	30.00	9.16–	10.00	0.38–	23.67	7.81–	15.40	0.70–	27.75	5.70–
(% of MVC)	±8.23	13.29	±37.31	69.16	±12.42	20.38	±40.99	75.50	±22.50	31.50	±24.45	55.57
RF Initial	9.80	0.30–	8.00	0.86–	5.13	0.19–	3.33	1.01–	5.30	1.06–	3.50	0.42–
(% of MVC)	±13.27	19.30	±8.43	16.86	±6.35	10.44	±5.77	17.68	±5.92	9.54	±4.72	11.02
VM Initial	16.60	3.90–	23.67	0.14–	7.13	2.02–	20.67	5.67–	9.20	4.23–	20.00	6.56–
(% of MVC)	±17.75	29.30	±22.68	47.47	±6.10	12.23	±35.79	79.26	±6.94	14.17	±19.25	46.56
ST Initial	3.80	0.27–	16.00	8.62–	3.38	0.06–	3.33	1.10–	4.50	0.64–	7.25	3.70–
(% of MVC)	±4.94	7.33	±27.26	44.62	±4.03	6.75	±5.77	12.68	±5.41	8.36	±9.14	21.80
Gmx Initial	7.60	1.14–	4.67	0.46–	2.50	0.05–	1.67	0.05–	2.70	0.82–	3.25	0.33–
(% of MVC)	±12.22	16.34	±4.88	9.79	±2.92	4.95	±2.88	8.84	±2.62	4.58	±3.94	9.53
Gmd Initial	16.60	0.73–	15.00	7.80–	9.75	0.75–	5.33	1.76–	10.20	2.24–	6.50	2.60–
(% of MVC)	±24.22	33.93	±21.72	37.80	±12.55	20.25	±9.23	28.28	±11.24	18.16	±7.89	19.06
EO Final	8.10	0.54–	17.67	13.28–	5.13	1.09–	2.00	0.61–	6.40	4.00–	22.25	12.43–
(% of MVC)	±10.56	15.66	±29.49	48.62	±7.43	11.34	±3.46	8.61	±4.83*	12.40	±8.81	28.64
IO Final	10.00	1.06–	5.83	0.30–	14.25	1.25–	3.33	1.10–	27.40	5.25–	51.00	38.7–
(% of MVC)	±15.46	21.06	±5.84	11.97	±15.55	27.25	±5.77	15.68	±11.96*	37.55	±14.60	65.17
ES Final	20.50	5.35–	23.33	9.52–	25.75	6.19–	9.67	3.19–	39.70	2.80–	9.25	2.54–
(% of MVC)	±21.17	35.65	±31.30	56.18	±23.40	45.31	±16.73	51.26	±31.57	66.60	±13.69	31.04
Mf Final	19.00	4.87–	33.83	7.26–	20.25	4.97–	20.33	6.71–	24.70	7.65–	25.25	13.11–
(% of MVC)	±19.75	33.13	±39.15	74.92	±18.27	35.53	±35.21	85.78	±23.83	41.75	±20.39	73.61
RF Final	4.70	1.27–	1.83	0.09–	6.50	2.85–	1.67	0.20–	5.80	1.37–	1.00	0.08–
(% of MVC)	±8.34	10.67	±1.83	3.76	±11.87	15.85	±1.15	3.54	±10.02	12.97	±1.15	2.84
VM Final	7.90	0.94–	3.67	0.67–	10.50	1.37–	3.67	1.21–	10.50	1.54–	4.75	2.19–
(% of MVC)	±12.36	16.74	±4.13	8.00	±14.20	22.37	±6.35	19.44	±12.52	19.46	±5.62	13.69
ST Final	8.00	2.17–	7.83	2.00–	8.13	0.37–	2.67	0.81–	9.30	3.18–	3.75	1.37–
(% of MVC)	±8.15	13.83	±9.36	17.66	±9.28	15.88	±4.61	14.14	±8.55	15.42	±4.34	10.67
Gmx Final	13.90	1.55–	4.83	0.07–	15.13	1.69–	3.00	0.09–	15.80	2.94–	4.75	2.20–
(% of MVC)	±17.26	26.25	±4.53	9.59	±20.11	31.94	±5.19	15.91	±17.98	28.66	±5.50	13.50
Gmd Final	16.30	4.29–	6.17	1.03–	25.38	0.88–	9.33	3.82–	22.20	1.81–	19.50	1.97–
(% of MVC)	±16.79	28.31	±6.85	13.36	±31.40	51.63	±16.16	49.49	±28.49	42.59	±17.24	38.07

Positive: Flexion, Abduction/Right obliquity/Side Flexion, Right/Internal rotation.
*Significant different.

Additional significant findings for the females included a significantly greater pelvis obliquity angle at final position ($p = 0.001$, $\eta_p^2 = 0.216$), reduced trunk flexion angle at initial position ($p = 0.001$, $\eta_p^2 = 0.377$), reduced trunk side flexion angle at final position ($p = 0.006$, $\eta_p^2 = 0.116$) and reduced trunk flexion angle at final position ($p = 0.001$, $\eta_p^2 = 0.246$), accompanied by a greater hip abduction angle at initial position ($p = 0.003$, $\eta_p^2 = 0.132$), and greater knee abduction angle at initial position ($p = 0.001$, $\eta_p^2 = 0.160$) in asymmetric lifting when lifting to the right. Females presented a greater pelvis rotation angle at final position ($p = 0.002$, $\eta_p^2 = 0.147$), reduced trunk flexion angle at initial position ($p = 0.001$, $\eta_p^2 = 0.315$), reduced trunk flexion angle at final position ($p = 0.001$, $\eta_p^2 = 0.261$), greater hip abduction angle at initial position ($p = 0.002$, $\eta_p^2 = 0.140$), and greater knee abduction angle at initial position ($p = 0.001$, $\eta_p^2 = 0.247$), accompanied by greater IO muscle activity at final position ($p = 0.010$, $\eta_p^2 = 0.189$), and greater EO muscle activity at final position ($p = 0.015$, $\eta_p^2 = 0.171$) in asymmetric lifting when lifting to the left.

Discussion

Our findings support that gender and the presence of existing rLBP influence lifting style. The female's differences in lifting response, coupled with their disproportionate decrease in lifting performance when compared to male counterparts, implies increased vulnerability to injury and subsequent clinical consequences. The result demonstrated that females engage in different lifting responses versus males, where the presence of rLBP appeared to amplify selected differences. It is important to identify, modify and adapt to these differences as a segue to improving lifting performance, reducing injury risk and potentially avoiding consequences of lifting in the presence of rLBP, especially in the female population.

Two significant interactions emerged from our findings. First, we observed a significant interaction between gender and group in Multifidus activity at the initial position during symmetrical lifting (Figure 2). Females with rLBP used their Multifidus to a great extent versus males, while healthy females used their Multifidus less than healthy males. This could indicate increased muscle use in attempt to stabilize the segments and to decrease trunk flexion, as evidenced by females using approximately 15 degrees less trunk flexion than males overall.(Kavcic et al. 2004; Moseley et al. 2002; Ward et al. 2009)

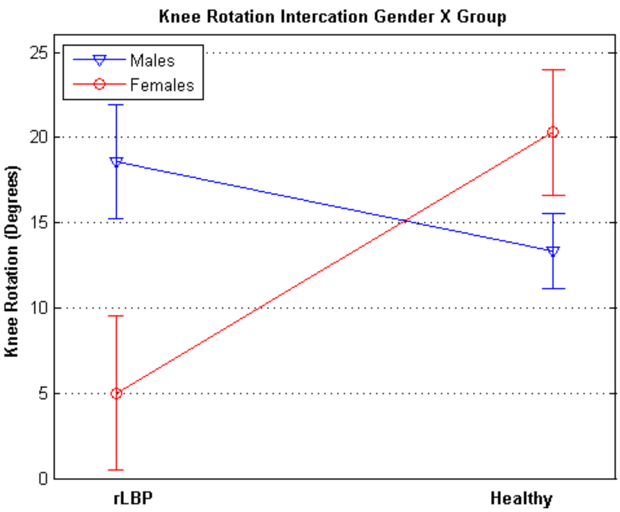

Figure 3. Significant two-way interaction effect between gender and group for knee rotation angle at final position in asymmetric lifting

Females with rLBP presented with less knee rotation versus their male counterparts in the final position of asymmetrical lifting, while healthy females presented more knee rotation versus healthy males (Figure 3). Upon further examination, one can note that rLBP did not appear to have a significant influence on knee rotation in male subjects during this asymmetric lift. This suggests that rLBP exerts a notable influence on this variable in females. This appears to be consistent with the females' observed increase in the use of knee abduction, where they moved more in the frontal versus transverse planes, as well as increased rotation at the pelvis during the same movement. These interactions reflect the females choosing a different total lifting style in the entire lower extremity and trunk, especially when troubled with rLBP.

Our significant gender main effects further support the females' choice to utilize a different lifting style. During the symmetrical lifting task, we observed females demonstrated less trunk flexion angle at initial position accompanied by increased pelvic obliquity and less trunk flexion angle at final position. In addition, we observed significantly more knee abduction during the initial and final lifting position. All of our findings may reflect differences in trunk and lower extremity control capabilities in the females during a lifting task. Two studies by Marras et al. (Marras et al. 2002; Marras et al. 2003) reported significantly different loading responses during a sagittal lifting task. These differences appeared to be related to compensations at the pelvis for the female subjects, possibly related to lower trunk strength capacity. Moreover, the investigators reported that the female subjects were closer to their expected lifting tolerances versus the males. These findings suggested that females are not simply proportionally scaled down versions of males, but rather exhibit different control strategies in response to the lifting load and demand.

Damecour et al. (2012) found that postural kinematics, trunk extensor muscle activity and subjective rating of both comfort and effort changed with differences in how their subjects executed during asymmetric two-handed reach in standing. Our significant gender main effects exhibited during the asymmetrical lifting tasks further support the females' choice to utilize a different lifting style. In a similar fashion to the symmetrical lifting task, we observed females demonstrated less trunk flexion angle at initial position accompanied by increased pelvic rotation and less trunk flexion angle at final position when the task was completed to both the right and left sides. Accompanying these trunk movement response findings were significantly increased hip abduction during the initial position and increased knee abduction at the final position when the task was completed to both the right and left sides. Finally, the same tasks produced significant increases in the females' IO and EO muscle activation versus the males in the final position. This again may suggest the females are functioning at a level closer to their maximum trunk capacity as earlier described, thus requiring increased muscle response.

Three group main effects were observed during the asymmetrical lifting task. We observed a significant group main effect for pelvis rotation at final position during right asymmetrical lifting, where the rLBP subjects demonstrated greater right pelvis rotation versus healthy subjects. In addition, we observed a significant group main effect for right hip adduction during the same task, where the rLBP subjects demonstrated greater right hip adduction versus healthy subjects. These finding work together; as the pelvis rotates right over fixed lower extremities, the right hip naturally adducts. Finally, we observed a main group effect for right EO activity during left asymmetrical lifting, where subjects with rLBP produced less EO muscle activity versus healthy subjects.

These group main effects suggest that the subjects with rLBP appear to demonstrate greater pelvis and hip movement and possible reduced dynamic stability during asymmetrical lifting, in contrast to using proximal stability and more distal movement and control. Other investigators have demonstrated increased unwanted pelvic movement during different functional strategies.(Scholtes et al. 2009) found that people with rLBP demonstrated increased maximal lumbopelvic rotation angle and earlier lumbopelvic rotation initiation versus healthy subjects during knee flexion and hip lateral rotation in a prone position. Similarly, Luomajoki et al. (2007, 2008) observed excessive, maladaptive lumbopelvic control during selected movement control tests in subjects with rLBP.

Maladaptive movement patterns in the lumbopelvic region appear to correspond with the incidence and persistence of rLBP.(Scholtes et al. 2009; Van Dillen et al. 2003) Evidence has been steadily growing that persistent rLBP disorders do exist where maladaptive movement and motor control impairments in the lumbopelvic region appear to result in ongoing abnormal tissue loading and mechanically provoked pain.(Burnett et al. 2004; Dankaerts et al. 2006; O'Sullivan 2005; Solomonow et al. 2003) These findings reflect a change in lumbopelvic control strategy that is similar to the findings in our study.

Due to our conservative alpha correction, several interactions and main effects were not significant but were below alpha level of 0.05. These findings may suggest changes in control strategies during lifting for females and individuals with rLBP. While we cannot draw definitive conclusions, the following variables are worth further investigation in the future. First, we observed the following two-way interactions between group and gender: pelvis rotation angle at final position ($p = 0.036$, $\eta_p^2 = 0.068$), and MG activity at final position ($p = 0.023$, $\eta_p^2 = 0.152$) in symmetric lifting; knee rotation angle at final position ($p = 0.048$, $\eta_p^2 = 0.061$ right), knee rotation angle at initial position ($p = 0.011$, $\eta_p^2 = 0.098$ left), Mf muscle activity at initial position ($p = 0.019$, $\eta_p^2 = 0.161$), and ES muscle activity at final position ($p = 0.047$, $\eta_p^2 = 0.118$) in asymmetric lifting.

Similarly, several group main effects merit additional investigation: ST activity at initial position ($p = 0.036$, $\eta_p^2 = 0.130$) in symmetric lifting; and hip rotation angle at initial position ($p = 0.029$, $\eta_p^2 = 0.073$), hip abduction angle at final position ($p = 0.013$, $\eta_p^2 = 0.093$) in the right side, pelvis rotation angle at final position ($p = 0.010$, $\eta_p^2 = 0.100$), EO muscle activity at initial position ($p = 0.025$, $\eta_p^2 = 0.148$), IO muscle activity at initial position ($p = 0.033$, $\eta_p^2 = 0.134$) and ST activity at final position ($p = 0.036$, $\eta_p^2 = 0.130$) in the asymmetric lifting (Table 2).

Several gender main effects suggest future additional investigation: pelvis rotation angle at final position ($p = 0.032$, $\eta_p^2 = 0.071$) in symmetric lifting; and pelvis rotation angle at final position ($p = 0.014$, $\eta_p^2 = 0.092$ right), trunk side flexion angle at initial position ($p = 0.029$, $\eta_p^2 = 0.074$), knee abduction angle at final position ($p = 0.024$, $\eta_p^2 = 0.078$), and EO muscle activity at initial position ($p = 0.015$, $\eta_p^2 = 0.171$) in asymmetric lifting (Table 3).

Limitations

Subjects in our study were not guided on lifting technique and the subject's box weight was determined by their maximum psychophysically acceptable weight. We limited our subject to lifting to a 1m height, with the aim to control for external validity. Our analysis focuses only on the subject's right side, thus assuming symmetry between sides. Additionally, we acknowledge limitations associated with use of a marker set that included skin movement, anthropometric model, system tracking error and data smoothing procedure error.

Conclusions

Females and individuals with rLBP appear to use different lifting styles that emphasize movement at the pelvis accompanied by poor kinematic control features at the hip, trunk and knee. While we did not observe changes in muscle coordination across the lower extremities, we did observe changes in core muscle control at the trunk (IO, EO and Mf). These findings exhibit the influence of gender and rLBP on trunk control, which may relate to the incidence and persistence of rLBP. Clinicians should be mindful of these changes when developing prevention and rehabilitation programs aimed at improving trunk control in preparation for lifting tasks during domestic and occupational activities. Future research should examine the influence of sensorimotor and functional training on these parameters in both normal individuals and those with rLBP for the purposes of injury prevention and rehabilitation.

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