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Novice Lifters Exhibit A More Kyphotic Lifting Posture Than Experienced Lifters In Straight-Leg Lifting

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Abstract

As torso flexion and repetitive lifting are known risk factors for low back pain and injury, it is important to investigate lifting techniques that might reduce injury during repetitive lifting. By normalizing lumbar posture to a subject's range of motion (ROM), as a function of torso flexion, this research examined when subjects approached their range of motion limits during dynamic lifting tasks. For this study, it was hypothesized that experienced lifters would maintain a more neutral lumbar angle relative to their range of motion, while novice lifters would approach the limits of their lumbar ROM during the extension phase of a straight-leg lift. The results show a statistically significant difference in lifting patterns for these two groups supporting this hypothesis. The novice group maintained a much more kyphotic lumbar angle for both the flexion (74% of the lumbar angle ROM) and extension phases (86% of the lumbar angle ROM) of the lifting cycle, while the experienced group retained a more neutral curvature throughout the entire lifting cycle (37% of lumbar angle ROM in flexion and 48% of lumbar angle ROM in extension). By approaching the limits of their range of motion, the novice lifters could be at greater risk of injury by placing greater loads on the supporting soft tissues of the spine. Future research should examine whether training subjects to assume more neutral postures during lifting could indeed lower injury risks.

Keywords

Spine; Lumbar; Occupational; Lifting

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Conflict of Interest Statement

The authors have no financial or personal conflicts of interest related to this work.

Introduction

Torso flexion and repetitive lifting are known risk factors for low back pain and low back injuries (Bernard, 1997; Hoogendoorn et al., 1999; Marras & Granata, 1995). Punnett et al. (1991) examined the trunk postures of automobile assembly workers and found low back disorders to be associated with tasks involving both severe and mild torso flexion. The risk of low back disorders also increased with duration. Since torso flexion and repetitive lifting cannot be completely removed, it is important to investigate what lifting techniques might reduce injury during repetitive lifting.

Coordination of the lumbar spine with trunk, pelvis, and whole body motions has been of particular interest to the physical therapy and rehabilitation community. It has been examined in a variety of motions including gait (Lamoth et al., 2004, 2006), rising from sit to stand (Shum et al., 2005), and lifting (Shum et al., 2007). It has been suggested by these authors that altered lumbar coordination strategies may be a factor in the low back pain injury population.

During a previous study in our laboratory (Maduri et al., 2008), healthy subjects' lumbar angle range of motion was measured by having subjects move from their most lordotic to most kyphotic lumbar postures while maintaining an upright torso position. This was repeated at several torso flexion angles to obtain a lumbar angle range of motion as a function of torso flexion. The lumbar angle normalized to this range of motion was then assessed in these subjects during repetitive, straight-leg, lifting tasks. This novel normalization scheme allowed the assessment of lumbar angle as it relates to the subjects' range of motion limits. It was found that subjects often approach the kyphotic limits of their lumbar range during the extension phase of lifting. It was speculated that such a pattern might elicit a stretch-shortening dynamic in the lumbar musculature that might make it energetically easier than remaining in the center of the range of motion. However, it was also speculated that this pattern could increase injury risk by putting additional strain on the extensor musculature and posterior ligamentous structures of the spine and higher moment loads on the intervertebral disks.

Past studies have examined differences between those with experience in repetitive lifting (typically within a workplace setting) and novice subjects to better understand strategies that might be useful in avoiding injury (Authier et al., 1995; Gagnon et al., 1996; Marras et al., 2006; Plamondon et al., 2010). It has been thought that these experienced lifters choose better lifting strategies, through experience, to avoid injury. It is also thought that those with poor lifting strategies that might lead to injury would not remain in activities or occupations that required repetitive lifting due to injuries also leading to better lifting strategies in an experienced population. These studies have shown that experienced lifters exhibit different lifting strategies than novice lifters (Authier et al., 1995; Gagnon et al., 1996; Marras et al., 2006; Plamondon et al., 2010). Gagnon et al. (Gagnon et al., 1996) found experienced lifters exhibited a knee flexion rather than a knee extension during the extension phase of a lifting task. Plamondon et al. (2010) found that novice lifters flexed their lumbar spine more than experienced lifters during a task where they transferred boxes from a conveyor to a trolley. This latter study demonstrated possible differences in lumbar-pelvic coordination between novice and experienced lifters that should be investigated further. In particular, does the greater flexion observed in novice lifters engage the limits of the lumbar range of motion?

In the current study, it was hypothesized that experienced lifters (defined here as experience in weightlifting rather than the workplace) would avoid the extremes of normalized lumbar angles observed previously in novice lifters (Maduri et al., 2008) and that novice lifters would approach the limits of their range of lumbar motion while the experienced lifters would maintain a more neutral spine during straight-leg lifts.

Methods

Subjects

Twenty three subjects completed this study (14 men, 9 women, age of 24.7±4 years, height of 1.71±0.10 m, and an average weight of 70.2 ±15.8 kg) with approval from the human subjects committee at the University of Kansas Medical Center and consent. Subjects were screened for musculoskeletal disease and a history of low back pain. On the day of testing they were asked to wear loose clothing, flat soled shoes, and no jewelry. Participants were categorized into two groups, experienced and novice lifters. An experienced lifter was someone who had lifted weights at least three times a week for the last year or more. Ideally, their weight lifting activities included dead lifts, bent-over barbell rows, standing curls, squats, and/or standing military presses, but in general most forms of free weights were considered adequate. The subjects that did not meet these criteria were considered novice lifters. Subjects were excluded from the novice lifters if they had been employed in a position that involved lifting or material handling for greater than three months at four hours per week or more. The experienced lifters group consisted of three women and eight men (average age of 25.2±4, height of 1.74±0.10 m, and weight of 75.7±15.4 kg) and the novice group included six women and six men (average age 24.2±4 years, height of 1.70±0.10 m, and weight of 64.9±14.5 kg).

Test Protocol

Data from a force plate (Bertech, Columbus, OH) was collected at 100 Hz. Electromagnetic motion sensors (MotionStar, Ascension Technologies, VT) were used to collect position and orientation data using Motion Monitor software (Innsport, IL). The motion sensor data was collected at 100 Hz and had a manufacturer reported resolution of 0.08 cm and 0.1° and an RMS accuracy of 0.76 cm and 0.5°. The sensors were placed on the skin at the thoracic level 10 (T10) and the sacral level 1 (S1) spinous process and on the skin at the manubrium with double sided tape. The height of the sensor on the manubrium was used to identify each lifting cycle and the T10 and S1 markers measured the trunk flexion angle and lumbar angle during the lifting activity. The flexion angle was defined by the angular deviation of a line intersecting the position of the T10 and S1 sensors from vertical. This line was part of a triangle that included the manubrium. The rotation of this triangle was broken down into the Euler angles with a rotation sequence of flexion (rotation in the sagittal plane)-lateral bending (rotation in the frontal plane)-axial rotation (rotation in the transverse plane). The flexion from these angles was defined as the flexion angle. As this is a predominately two dimensional motion, it was expected that there would be little rotation out of the sagittal plane. The lumbar angle was based on the rotational orientation of the T10 and S1 sensors. Using a similar Euler angle sequence, the three-dimensional Euler angles were determined for the T10 and S1 sensors and the difference between the rotation in the sagittal plane (flexion angle) of each sensor was used to define lumbar angle. (Figure 1) These definitions were consistent with previous literature descriptions (Granata & Sanford, 2000; Gade, 2007; Maduri, 2005; Maduri et al., 2008).

The range of lumbar curvature for each subject was found using the method described by Maduri et al. (Maduri et al., 2008). This involved having subjects flex their trunk to reach trunk flexion angles of 0°, 30°, 60°, and 80° as the trunk flexion angles were displayed in real time. The subject would then hold the trunk flexion angle constant while rotating their pelvis and thorax to reach their maximum (kyphotic) and minimum (lordotic) attainable lumbar angles. Once the subject was comfortable with this task, these extremes were measured three times and averaged. These averaged values were defined as the maximum and minimum attainable lumbar angle values for the subject and used to normalize the future lumbar angles as a percentage of the range between the minimum and maximum lumbar angle. For lumbar angles at torso flexion angles between the measured flexion angles of 0°, 30°, 60°, and 80°, the maximum and minimum values were linearly interpolated from their nearest neighbors. Figure 2 shows an example of the raw lumbar angles and the same values after normalization.

This experimental protocol included: 1) measurement of maximal lifting force, 2) measurement of spinal range of motion at four trunk flexion angles (0°, 30°, 60°, and 80°), and 3) a lifting task.

To measure maximal lifting force, participants were asked to stand on a force plate and pull up on a rope located just below their knees for five seconds, while avoiding knee flexion. The mean of the highest 50 data points was defined as the maximum amount of upward force the subjects could exert. Three percent of this maximum force was used as the lifting load throughout the rest of the experiment. Weights approximately equal to 3% of this maximum force were placed in a crate for the lifting task (0.57–3.4 kg, mean 1.5±0.8 kg). The crate used for the remaining lifting task was a 38 cm long × 34 cm wide × 28 cm tall crate with handhold cutouts at 25 cm from the base.

Participants then completed straight legged lifts for four minutes, while listening to a metronome to maintain a rate of 15 lifts/minute. They were instructed to perform straight-leg lifts but were not given any instructions on lumbar posture or lumbar-pelvic coordination in order to obtain their preferred lumbar-pelvic lifting strategy. The investigators visually monitored the subjects for compliance with the straight leg lift. The participants were asked to raise the crate from floor to waist level, pause, and then lower the crate to the floor for a complete lift.

Analysis

The vertical height of the manubrium sensor was analyzed to pinpoint the time indices for the flexion phase and the extension phase of each lift cycle. Each time the sensor's vertical height reached a minimum represented the time at which the subject reached the bottom of their lift (flexion angle ~80°) and each maximum of the sensor's vertical height represented the time at which the subject reached the top of a lift (flexion angle ~0°). These indices were used to distinguish each lift individually and to single out the extension phase of each lift. Lumbar angles (LA) were normalized using the range of motion (ROM) values (described above) with the following equation:

$$Normalized\ LA = \frac{LA - LA_{min}}{LA_{max} - LA_{min}} * 100$$

This normalization gives a lumbar angle of 0% when a subject's lumbar angle is at the lordotic extreme and 100% at the kypthotic extreme of the lumbar ROM for any give torso flexion angle. The first three full lift cycles were examined.

Normalized lumbar angle values during extension and flexion were grouped into four quadrants depending on their corresponding trunk flexion angle: 10–25°, 26–40°, 41–55°, 56–70°. The normalized lumbar angles were averaged together within these groups. A repeated measures ANOVA was performed on the normalized LA averages with the independent variables, group, gender, flexion angle quadrant (repeated), and three lifting cycles (repeated). Only the first three quadrants were used in this ANOVA as one subject did not reach the fourth quadrant. A significance level of $p < 0.05$ was considered statistically significant. Post-hoc tests of within-subjects contrasts were performed for statistically significant findings.

Results

Novice lifters exhibited a significantly more kyphotic lifting posture during both the extension and flexion phases of the lift when compared to the experienced group (Table 1, Figure 3). The novice lifters began the flexion phase of a lift near the middle of their ROM (58.6%) but quickly climbed to the limits of their range at the end of the flexion phase (84.2%). During extension, novice lifters spent most of the lift in a kyphotic posture relative to their range (88.6–91.9%) before ending the lift only slightly more neutral (70.6%). Experienced lifters maintained a lordotic posture relative to their range during the flexion phase of a lift, starting low (32.3%), becoming slightly more neutral (34.1–40.8%). For the extension, experienced lifters remained neutral relative to their range (42.4–52.0%) for most of the lift.

A statistically significant difference ($p<0.01$) was found between the experienced and novice groups and for the direction of the lift (extension or flexion) ($p<0.01$). The lifting cycle was not significantly different, as would be expected. There was no significant difference for gender. Finally, there were no significant interactions between the independent variables (Table 2).

It is possible that the differences observed between the two groups could be due to differences in the ranges of motion of the lumbar angle. To examine this, a secondary ANOVA of the lumbar angle range of motion with the independent variables of flexion angle and group was performed and found no statistical difference between the ROM of the two groups (Figure 4).

Discussion

For this study, it was hypothesized that experienced lifters would maintain a more neutral lumbar angle relative to their range of motion, while novice lifters would approach the limits of their lumbar ROM during the extension phase of a straight-leg lift. Our results show a statistically significant difference in lifting patterns for these two groups supporting this hypothesis. The novice group maintained a much more kyphotic posture for both the flexion and extension phases of the lifting cycle, while the experienced group retained a more neutral lumbar angle throughout the entire lifting cycle (Figure 3).

There have been many studies aimed at identifying the differences between novice and experienced lifters, with the intention of learning what might be taught to the novice lifters to reduce their risk of injury (Granata & Marras, 1999; Lee & Nussbaum, 2013; Marras et al., 2006; Plamondon et al., 2014). In one study (Marras et al., 2006), spinal compressive loading was assessed for a variety of lifting frequencies and spinal compressive loads were found to decrease when subjects lifted with a more familiar frequency. Novice lifters, when forced to lift at an unfamiliar frequency showed more simultaneous muscle contractions as opposed to sequential, which has been shown to increase spinal compressive loading (Parakkat et al., 2007). These authors suggested that novice lifters had underdeveloped motor control strategies. Lee and Nussbaum (2013) found that experienced workers' movements seemed to place greater emphasis on maintaining total body balance and torso stability. Whereas novice workers seemed willing to sacrifice this stability in order to maintain more constant torso kinematics or kinetics over the range of tasks performed. Another study (Plamondon et al., 2014) showed that experienced lifters do flex their lumbar spine 10 degrees less than novice lifters. In the current study, one can compare the difference in lumbar angle in each quadrant with quadrant one to compare it with the findings of Plamondon et al. Doing this one finds the experienced lifters have 8.9 degrees less flexion than the novice lifters. The results show a good correspondence to the Plamondon paper, despite differences in the lifting task and the experienced population definition. What is unique in the current study, however, is that one can further say, through the examination of the lumbar angle normalized to the range motion, that the novice lifters approached the limits of their ROM at an average of 86% of lumbar angle ROM during trunk extension whereas the experienced lifters maintained a neutral posture at an average of 48% of lumbar angle ROM.

In the current study, experience was defined as experience in weight lifting exercise rather than experience in workplace settings, as several other authors have used. Weight lifting was used to define experience because it is a consistent lifting activity that is useful in examining intrinsic changes in lifting coordination. An experienced workplace population may have more varied job duties and, as such, future studies examining these patterns in an experienced workplace population might be useful.

Panjabi (1992) divided spinal motion into two regions: the neutral zone and the elastic zone. The neutral zone is a region near neutral spinal posture where there is little internal resistance to intervertebral movements for a passive spinal column. The elastic zone occurs with greater deformation when there is an increase of internal resistance to further movement. Soft tissue limitations, such as facet joints, ligaments, and the intervertebral disks themselves, begin to restrict further rotation in this zone. Additionally the passive components of the musculature can also act as soft tissue limits. Going to the extremes of lumbar motion, as was observed in the novice subjects of this study, could potentially move the spine posture from the neutral zone to the elastic zone, engaging and loading these soft tissues.

Solomonow et al. (1998) examined one such soft tissue limit, the supraspinal ligament. These authors showed that mechanical deformation of this supraspinal ligament results in a reflexive activation of the nearby paraspinal muscles in an attempt to limit any movement that would bring the vertebrae out of their natural alignment. As such, these tissues also serve an important role in stability and control of spine motion. It has been shown that repeated stretching of these ligaments, such as could occur with repetitive lifting tasks, drastically diminished the stabilizing reflexes, 85% in the first five minutes, potentially reducing their ability to stabilize the spine (Solomonow et al., 1999). For the novice lifters in our study, repetitive lifting strategies that repeatedly go towards the elastic zone could, therefore, not only increase loading and strain of the ligaments but also alter the reflexes that provide stability to the lumbar spine, predisposing such a population to injury.

It could be hypothesized that the preference of novice lifters to a more kyphotic posture is due to a greater mechanical efficiency that this movement could provide. Stretch-shortening cycles have been well documented for other activities (Avela et al., 1996; Harrison et al., 2004; Jacobs et al., 1993) and if subjects are able to initiate a similar cycle during repetitive lifting it could account for the kyphotic posture’s common use. Stretch-shortening would result in stretching of the back muscles. This allows a person to briefly store the elastic energy of the muscles and nearby tendons to be released along with the muscle contraction. However, this activity has also been associated with a risk of injury as eccentric contractions are known to cause muscle damage (Chapman et al., 2008; Dessem et al., 2010).

In this study, a straight leg lifting strategy was examined. As such, changes in lumbar angle at a given torso flexion angle should be due to coupled rotation of the pelvis and the thorax. However, it is important to look at these lumbar coordination patterns in bent knee lifting as well. Maduri (2005) examined the lumbar angle ROM with a knee flexion of 45 degrees and found that the ROM was not statistically different from that with straight legs. The author further assessed normalized lumbar angles, using the methods described in this study, for lifting tasks where subjects were asked to repetitively lift with a peak knee flexion of 45 degrees. A similar pattern in these subjects was observed with an 82% maximum normalized lumbar angle during extension.

One potential limitation of this study was that static lumbar ROM was used to normalize the dynamic lumbar angles recorded during the lifting task. For some subjects, their dynamic ROM appeared to be larger than their static ROM, resulting in normalized lumbar values greater than 100%. Regardless, this study was able to demonstrate that novice and experienced lifters do employ different lumbar-pelvic coordination strategies. Additionally, it was found that the ROM measured for the two groups was not different, confirming that the difference lies in the coordination strategy. Another limitation is the uneven numbers of men and women in the experienced group. However, examination of gender in the ANOVA did not demonstrate a statistically significant difference with gender.

Future work should involve an examination of the energetics of the self-selected lifting strategy to see if novice lifters use this pelvis-first, lumbar-pelvic coordination strategy to perform the task more metabolically efficiently. Additionally, a biofeedback training method could be developed to teach neutral lumbar coordination. The effectiveness of such training in reducing incidence of low back injuries could be evaluated. How the lifting patterns change over time could also be evaluated, studying the effects of fatigue on lumbar coordination. Finally, future studies could examine the normalized lumbar angle measure in both actively symptomatic and no longer symptomatic, low back pain patient populations.

In conclusion, this study demonstrated that novice and experienced lifters do maintain different lumbar angles relative to their lumbar ROM during cyclic, straight-leg, lifting. Subjects with more lifting experience had a more neutral lumbar spine while novice lifters remained more kyphotic for both the flexion and extension phases of a lifting cycle. This resulted in novice lifters approaching the limits of their ROM, potentially increasing their spinal instability and risk of lower back injury.

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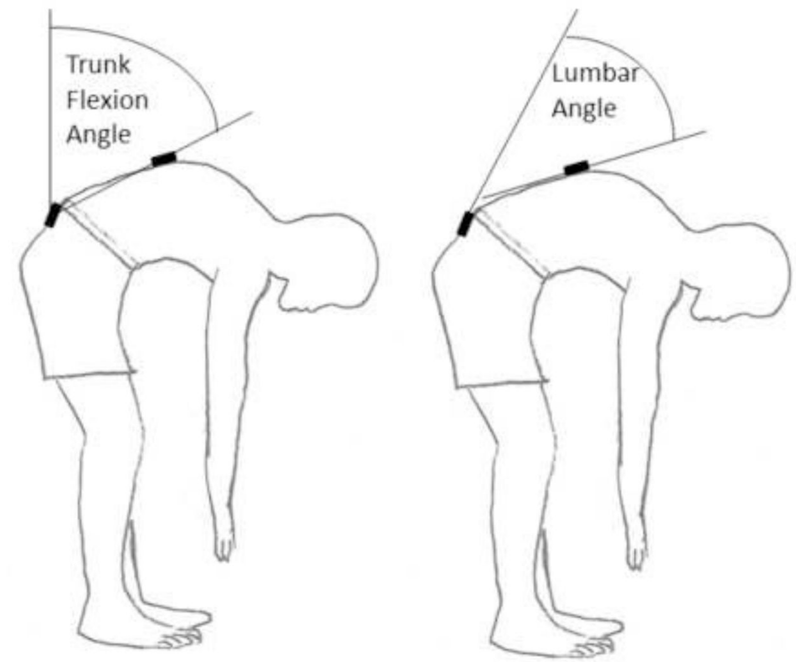

Figure 1.

Electromagnetic sensors were placed on the T10 and S1 spinous processes. These sensors return position and orientation. The relative position of the S1 sensor to the T10 sensor was used the determine the torso flexion angle (left). The relative anglar orentation of the 10 sensor to the S1 sensor was used to determine lumbar angle (right).

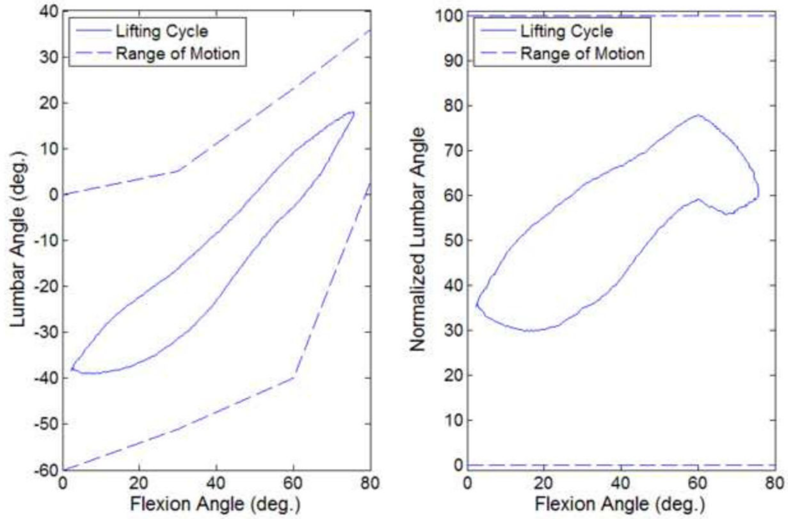

Figure 2.

Lumbar curvature was measured for each subject. This figure represents a typical lifting cycle (left chart) that has been normalized using the subject's range of motion (right chart).

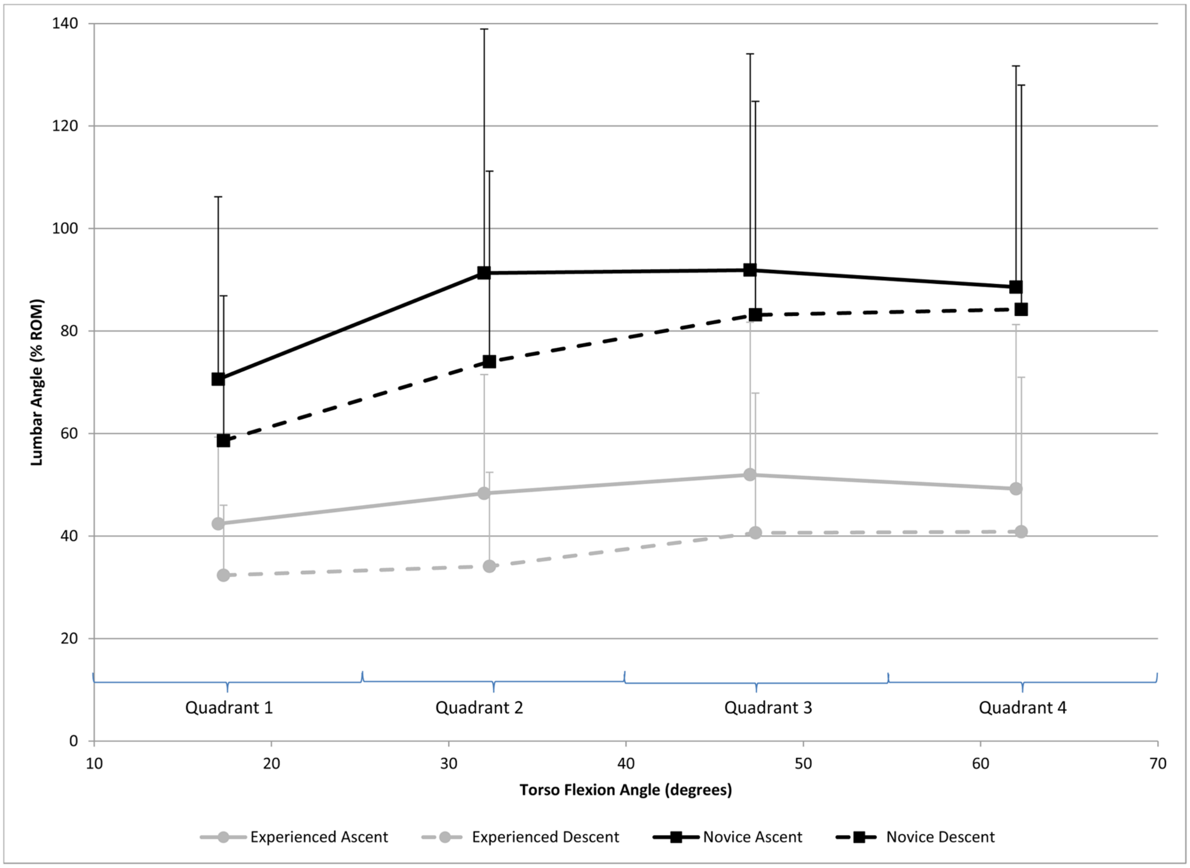

Figure 3.

Normalized lumbar angle for experienced and novice lifters during lifting is represented in this chart as a function of torso flexion angle for both the ascent and descent of the lifting cycles. It can be observed that novice lifters have lumbar angles near the kyphotic limits of their range of motion while experienced lifters have lumbar angles near the middle of their range.

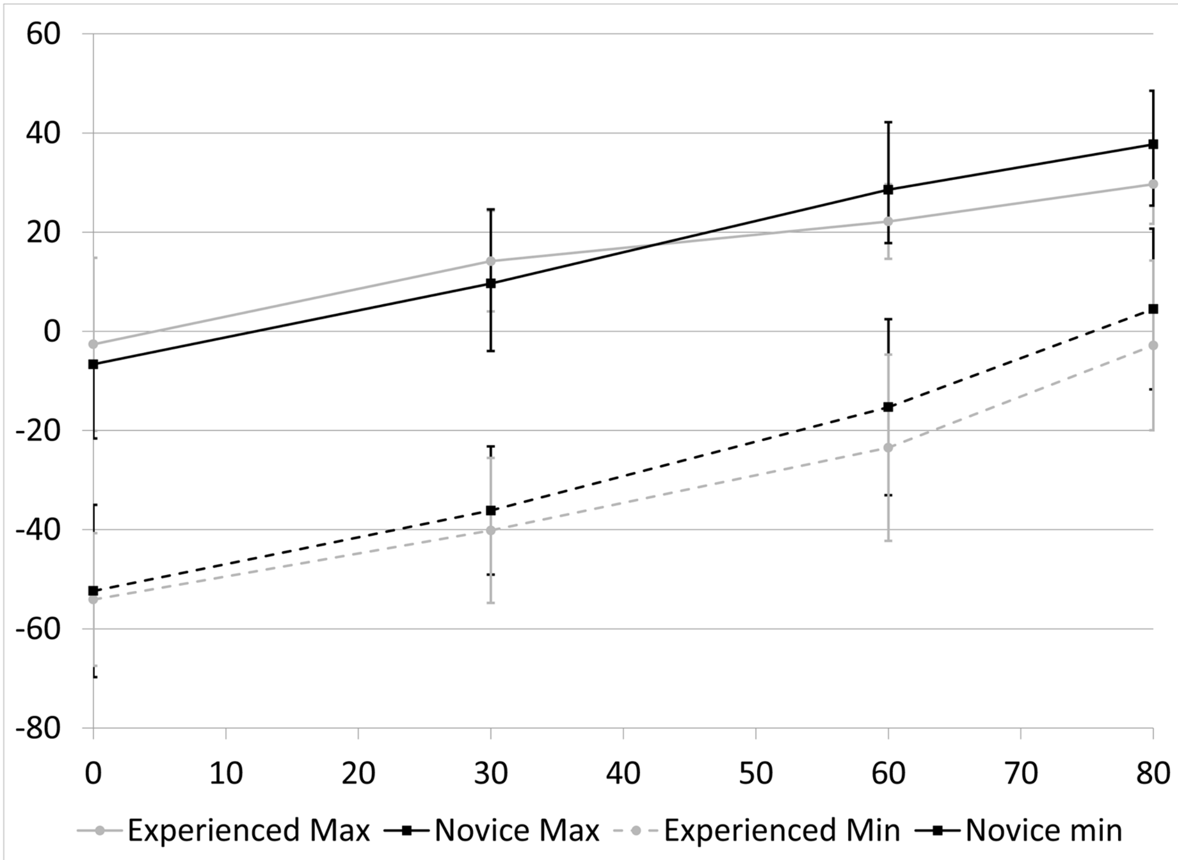

Figure 4.

The range of motion (ROM) for experienced and novice lifters is represented in this chart with the standard deviation shaded in their respective colors. The top two data sets are for the kyphotic limit of the range and the bottom two data sets are for the lordotic limit of the range. The ROM for experienced lifters was not significantly different from that for novice lifters.

Table 1

Averages and standard deviations of the lumbar angles (in degrees) and the normalized lumbar angles (in % ROM) for four lifting cycles in each of the four trunk flexion angle quadrants (Quadrant 1: 10–25°, Quadrant 2: 26–40°, Quadrant 3: 41–55°, and Quadrant 4: 56–70° of trunk flexion). During the ascent phase, novice lifters exhibited normalized lumbar angles above 90% in quadrants 2 and 3, while experienced lifters had normalized lumbar angles around 50% of their range.

	Descent Phase				Ascent Phase			
	Quad 1	**Quad 2**	**Quad 3**	**Quad 4**	**Quad 4**	**Quad 3**	**Quad 2**	**Quad 1**
Novice (Lumbar Angle (deg))	−18.8±12.3	−4.7±14.6	9.3±18.3	18.4±19.1	20.0±17.3	13.1±16.5	1.6±15.1	−14.4±13.7
Novice (Normalized Lumbar Angle (% ROM))	58.6±28.3	74.0±37.2	83.1±41.7	84.2±43.8	88.6±43.2	91.9±42.2	91.3±47.6	70.6±35.6
Experienced (Lumbar Angle (deg))	−27.6±12.3	−19.1±10.7	−8.73±14.8	−3.3±16.1	0.1±16.5	−2.9±15.0	−11.7±11.2	−22.2±10.5
Experienced (Normalized Lumbar Angle (% ROM))	32.3±13.7	34.1±18.4	40.6±27.2	40.8±30.1	49.2±32	52.0±29.8	48.3±23.2	42.4±16.9

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Table 2

A Huynh-Feldt, repeated measures ANOVA was performed to examine the effects of experience level (novice versus experienced), direction (flexion versus extension), torso flexion angle quadrant (10–25°, 26–40°, and 41–55°), and cycle (repeated lifting cycles) on the normalized lumbar angle. Quadrant 4 was excluded from this analysis as not all subjects had torso flexion in this range. Highlighted $p<0.05$ values demonstrate that experience and direction were significant while cycle and quadrant were not.

	p-value
Experience Level	**< 0.01**
Gender	0.420
Direction	**< 0.01**
Direction*Experience Level	0.931
Direction*Gender	0.387
Quadrant	0.083
Quadrant*Experience Level	0.068
Quadrant*Gender	0.821
Cycle	0.740
Direction*Quadrant	0.264
Direction*Cycle	0.117
Quadrant*Cycle	0.329