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The Effect of Stance Width on Trunk Kinematics and Trunk Kinetics during Sagitally Symmetric Lifting

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Abstract

Lifting technique can have a significant impact on spine loading during lifting. The sports biomechanics literature has documented changes in trunk and lower extremity kinematics and muscle coactivation patterns as a function of stance width during high force dead lift and squat exercises. The focus of the current study was to explore whether these lifting stance width effects might translate into the occupational setting under more moderate load level conditions. Twelve subjects performed repetitions of a sagittally symmetric lifting and lowering task (10 kg load) under three stance width conditions: narrow (feet together), moderate (feet shoulder width) and wide (feet 150% of shoulder width). As they performed these exertions, trunk kinematics were captured using the lumbar motion monitor while the activity of the trunk muscles (erector spinae, rectus abdominis) and lower extremity muscles (gluteus maximus, vastus lateralis and vastus medialis) were evaluated using normalized electromyography. The results showed that both the range of motion and peak acceleration in the sagittal plane were significantly affected by the stance width. The muscle activation levels, however, were not significantly affected by the stance width. These results collectively would indicate that the stance width effects seen in power lifting activities do not translate well into the occupational environment where more moderate loads are typically lifted.

Relevance to industry: Exploring alternative lifting strategies may provide an opportunity to reduce the incidence of low back disorders. Lifting stance width is one variable that has not been explored in the ergonomics literature.

Keywords: lifting stance; electromyography; low back injury

1. Introduction

Low back pain is a common musculoskeletal pain complaint in occupational settings. Sengupta and Reno (2007) estimated that the employers in the United States paid $87.4 billion in worker's compensation costs in 2004 due to low back pain. It is recognized that employees involved in manual materials handling are exposed to a number of risk factors for low back pain such as heavy physical work, forceful movements, and awkward trunk postures (Bernard, 1997). It is also recognized that lifting technique has the capacity to change the level of exposure to some of these risk factors by altering trunk posture and moments generated by the external load.

While there have been a number of studies that have considered the differences between the stoop and the squat lift technique (often with conflicting recommendations) (van Dieen et al., 1994; Dolan et al., 1994; Anderson and Chaffin, 1986; de Looze et al., 1998; Adams and Hutton, 1986), one characteristic of occupational lifting technique that has not been considered is lifting stance width (herein defined as the distance between the feet in the medial-lateral direction with sagittal symmetry of stance). There have been a number of studies in the sport and exercise fields that have noted significant differences in the systems-level biomechanics (interaction between lower extremities and low back) when stance width is varied during various power lifting exercises. In an evaluation of subjects participating in the 1989 Canadian Powerlifting Championships, Cholewicki et al. (1991) noted that these trained power lifters performing a deadlift exercise (an exercise wherein a barbell load lifted from the ground to mid-thigh height) using a wide stance style generated significantly lower L4/L5 moments (~10% lower) and calculated an 8% reduction in L4/L5 shear force as compared to the conventional stance (~ shoulder width) dead lift. In a study of 12 “sumo” (i.e. wide stance) and 12 conventional style deadlift experts, Escamilla et al. (2000) observed that at both lift-off and as the load passed the height of the knee the sumo style of deadlift resulted in a 5-10 degree reduction in trunk flexion as compared to the conventional stance lift. In a study of a squat exercise (a barbell load placed across the shoulders behind the neck), McCaw and Melrose (1999) noted a significant increase in gluteus maximus muscle activity with a heavy load under a wide stance conditions as compared to a more traditional stance width. These authors postulated that the hip abduction and lateral rotation associated with a wider stance put the gluteus maximus in a less efficient length thereby reducing its force producing potential. Collectively, these studies from the exercise science literature indicate interesting effects of stance width on trunk and lower extremity biomechanics.

What is unclear is how these kinds of effects may manifest themselves during occupational lifting tasks where the magnitude of the load being lifting is different by an order of magnitude. Therefore, the purpose of the current study is to evaluate the effects of stance width on the kinematics and muscle activation patterns of the low back and lower extremities during an occupationally-relevant lifting task. It was hypothesized that stance width would significantly alter the muscle activation levels of both the trunk musculature and the lower extremity musculature. It was also hypothesized that the wide stance would reduce the sagittal plane range of motion and value of the peak sagittal plane acceleration of the lumbar spine.

2. Methodology

2.1. Brief Overview of Protocol

There were two phases to this experiment: a static weight-holding phase and a dynamic lifting phase, and both were conducted in the same visit to the laboratory. The static weight-hold tasks were performed to evaluate the effects of lifting stance width on the muscle activation profiles using surface electromyography while the dynamic lifting tasks were conducted to evaluate the effect of lifting stance width on lifting kinematics.

2.2. Participants

Twelve male subjects were recruited from the graduate and undergraduate student population at Iowa State University. Subjects had a mean (SD) age of 25.8 years (3.1), stature 179.0 cm (5.4) , and whole body mass of 77.7 kg (13.8). Each signed a written informed consent form and reported having no current or chronic lower back or lower extremity problems. After signing the informed consent the subject's shoulder width was measured (acromioclavicular joint to acromioclavicular joint) . The mean (SD) shoulder width of the subjects was 54.4 cm (2.5).

2.2. Apparatus

2.2.1. Data Collection Apparatus

Both trunk kinematics and muscle activation profiles were collected during the lifting tasks in this study. Trunk kinematic data were collected using the Lumbar Motion Monitor (LMM) (Chattanooga Group Inc., TN). The LMM provides lumbar kinematics data that includes instantaneous trunk angle, trunk angular velocity and trunk angular acceleration in the sagittal, coronal and transverse planes. In the current study only sagittal plane kinematics were analyzed. These data was collected at 60 Hz. Electrical activity of selected trunk and lower extremity muscles was collected using surface electromyography (EMG) (Model DE-2.1 Bagnoli™ from DelSys, Boston, MA). These EMG data were collected at 1024 Hz.

2.2.3 Lifting Task Apparatus

The object to be lifted was a 10 kg plastic crate with handles (good coupling). A wooden block was placed along the front edge of the box and subjects were instructed to keep their toes up against this block to maintain a consistent positioning of the load relative to the lifter (15cm). During the static holding trials, wooden platforms were developed to set the crate such that the hand heights were (33cm, 48cm and 64cm). During the dynamic trials, the lifter lifted the box from the floor (starting hand height 33cm) to knuckle (~mid thigh) height. During both the static and dynamic trials the subjects were informed to perform the task with a "natural lifting technique." This was done in order to see the effect that lateral stance width alone had on the kinematics and muscle activity rather than how lateral stance width would affect a specific lifting technique (i.e. stoop or squat)

2.3. Experimental Design

2.3.1. Independent Variables

For the static weight-holding trials there were two independent variables: STANCE WIDTH and LOAD HEIGHT. STANCE WIDTH had three levels: feet together, shoulder width, and feet 150% of shoulder width. LOAD HEIGHT had three levels: (33cm, 48cm and 64cm). In the dynamic lifting trials only STANCE WIDTH was considered and the same levels of width were used.

2.3.1. Dependent Variables

The dependent variables for the static weight-holding trials were normalized (to maximum), integrated EMG (NIEMG) of the muscles of the low back and lower extremity. Since this was a sagittally symmetric lifting task the bilateral pairs of each muscle were averaged together resulting in five dependent variables: the right-left averages of the erector spinae (ES), the rectus abdominis (RA), the gluteus maximus (GM), the vastus medialis (VM), and vastus lateralis (VL). The four dependent variables for the dynamic lifting trials were: 1) the peak sagittal trunk angle achieved during the lifting motion (concentric), 2) the peak sagittal trunk angle achieved during the lowering motion (eccentric), 3) the peak sagittal acceleration achieved during the lifting acceleration phase of the concentric range of motion, and 4) the peak sagittal deceleration achieved as the subject was reaching the end of the lowering motion.

2.4. Experimental Task

2.4.1. Static Holding Trials

Upon completion of a brief warm-up, surface electrodes were placed over the bilateral erector spinae and rectus abdominis muscles. Subjects then completed two isometric maximum voluntary contractions (MVCs) for both the erector spinae muscles (attempted trunk extension) and rectus abdominis muscles (attempted trunk flexion) against the resistance provided by an isokinetic dynamometer while the torso maintained a flexion angle of 30 degrees. After completion of the erector spinae MVCs, the subjects then used a strap that was secured to the arm of the dynamometer and the subject performed a maximal trunk flexion exertion against this strap.

Subjects were then released from the dynamometer and surface electrodes were placed over the bilateral vastus lateralis, vastus medialis, and gluteus maximus. MVC exertions were performed against manual resistance provided by the experimenter. For the knee extensors the subject assumed a seated posture with knee at 90 degrees and performed a knee extension while the experimenter secured the shank. For the gluteal MVCs the subject stood and attempted hip extension against the manual resistance provided by the experimenter at the ankle.

Subjects then proceeded to the lifting area. Subjects were instructed to place their feet against the toe board at the stance width as defined by the randomized sequence for that subject. They then flexed forward and grasped the box (height also determined by the randomized sequence) and lifted the box 3cm and then held the box in that position for three 3 seconds while the muscle activities were collected (Figure 1). A break of 30 seconds was provided as the height and stance width was set for the next trial. There were two repetitions per condition for a total of 18 static trials.

Insert Figure 1 about here

2.4.2. Dynamic Lifting Trials

Upon completion of the 18 static weight-holding trials the surface electrodes were removed and the subjects donned the LMM. Time was allowed for familiarization with the LMM, in which participants were encouraged to lift the box with their feet aligned using the three stance width conditions. Baseline lumbar angles were collected as the participants stood in an upright, neutral posture. Participants then moved back to the lifting area and were instructed to place their feet against the toe board at the stance width as defined by the randomized sequence for that subject. They then flexed forward and grasped the box and lifted the box to a full upright posture, held the postures for 2 seconds and then returned to the box to the floor. A break of 30 seconds was provided as the stance width was set for the next trial. There were four repetitions per condition for a total of 12 dynamic trials. Upon completion of the 12 lifts, the static, upright measurement was again collected.

2.5. Data Processing

2.5.1. Electromyographic Data

The unprocessed EMG data were band-pass filtered at a low-pass frequency of 500 Hz and a high-pass frequency of 10 Hz. A notch filter was also applied that eliminated 60 Hz and its aliases and then these filtered signals were full-wave rectified. The EMG signals from the MVC trials were reduced to 1/8th second windows and the maximum of these 1/8th second windows was the value used as the denominator in order to normalize the EMG data from the experimental trials. The numerator of these NIEMG was the steady state muscle activity as the subjects held the weight in position. These normalized values of the bilateral pairs were then averaged.

2.5.2. Lumbar Motion Monitor Data

Peak sagittal angle during lifting was determined as the greatest sagittal angle as the participant bent down to lift the load and peak sagittal angle during lowering was determined as the greatest sagittal angle as the participant bent back down to place the load on the ground. To control for individual differences in LMM placement and lumbar lordosis, the upright, neutral, baseline values for each participant were subtracted. Peak angles and accelerations during the concentric and eccentric lifting motions were then found. Peak acceleration during the lifting phase was defined as the peak acceleration during the first 10° of the concentric lifting motion. Peak deceleration was defined as the peak acceleration value during the last 15° of the eccentric lifting motion.

2.6. Statistical Analysis

All statistical analyses in this study were conducted using SAS (SAS Institute, Cary, NC). Prior to formal statistical analysis, the assumptions of the ANOVA procedure (normality of residuals assumption, non-correlation of residuals (i.e. independence) assumption, and constant variance of residuals assumption) were tested (Montgomery 2005, pp.76-79). Dependent variables that violated one or more assumption were transformed so that the ANOVA assumptions were no longer violated (Montgomery 2005, p.80).

Multivariate analyses of variance (MANOVAs) were then conducted on all response measures to control the experiment-wise error rate. Only those independent variables found to be significant in the MANOVA were pursued further in the univariate ANOVA. Bonferroni post-hoc tests were then performed on the significant main effects to further explore the nature of these significant effects. A criteria p-value of 0.05 was used in all statistical tests.

3. Results

3.1. Static Holding Trials

Analysis of the data from the static weight-holding trials revealed that neither the interaction between STANCE WIDTH and LOAD HEIGHT nor the main effect of STANCE WIDTH had a significant effect on the NIEMG of the muscles sampled (Table

1.) LOAD HEIGHT did have a significant effect on these NIEMG values for all muscles considered (Table 1 and Figure 2). The response of the ES fairly clearly shows the flexion-relaxation phenomenon with relatively low muscle activity levels at the lowest load positions, while the vasti showed a consistent increase (~60%) in activity at the lower load positions.

Insert Table 1 and Figure 2 about here

3.2. Dynamic Lifting Trials

Analysis of the data from the dynamic lifting tasks revealed a significant STANCE WIDTH main effect for all kinematic dependent measures indicating a significant impact of stance of the lifting technique chosen by the participants (Table 2 and Figures 3 and 4). Participants chose to use a greater (~17% greater) lumbar sagittal flexion strategy in the narrow stance condition as compared to the wide stance condition. Given the 15cm distance between the lifter's toes and the front edge of the crate, this is not likely to be attributable to interference of the knees with the crate during lifting. There was a 5% reduction in sagittal angle when the stance was increased from shoulder width to the wide stance condition. In terms of the peak acceleration, data from both the lifting and lowering exertions showed a strong impact of STANCE WIDTH on the magnitude of the peak acceleration/deceleration. During the lifting phase the wide stance condition generated peak acceleration values that were only 80% of those seen in the narrowest stance condition, and during the lowering phase the peak deceleration values during the wide stance were 85% of those in the narrow stance condition.

Insert Table 2 and Figures 3 and 4 about here

4. Discussion

The purpose of the current study was to evaluate the effects of stance width on the systems biomechanics of the low back and the lower extremity. Based on the results seen in the exercise science literature, it was hypothesized that a wide lifting stance would impact the interaction between the low back and the lower extremity in terms of both kinematics and muscle activation levels. Our results showed that there were significant changes in the sagittal plane kinematics, but no effect on the muscle activation levels as a function of stance width.

One possible reason for the null effect on muscle activation is amount of weight being lifted. This study used a weight of 10 kg. Much of the research in the exercise science literature investigating the effects of stance width on lifting biomechanics used considerably larger loads (Escamilla et al. 2000, 2001; McCaw and Melrose, 1999). McCaw and Melrose (1999) observed an increase in GM activity with a wide stance but did not see the response at lower load levels. Another possible factor that could have led to these inconsistent results is the standardization of lifting technique seen in these previous studies. In this exercise science literature, the technique used during the exercises is often controlled or performed by elite athletes with highly developed technique (Escamilla et al. 2000; 2001; 2002; McCaw and Melrose 1999). Escamilla et al. (2000,2001,2002) and McCaw and Melrose (1999) used experienced weight lifters who used similar mechanics for each lift. In the current study, the participants were neither trained athletes nor were they asked to perform the lift using any particular style. Lifters were instructed to lift with a "natural" technique. This could have been a stoop style, squat style or something in between. This variability in technique may have led to higher degrees of variability in trunk muscle activation levels which could make it more difficult to find statistically significant differences.

The static weight-holding data also revealed some significant differences among load heights. There were several significant effects, but most were at or below 5% MVC. The ES showed significant findings as the height increased - as the height increased, so did ES activity. This is most likely due to the passive tissues of the low back accounting for more of the back extension moment as the posture became more flexed indicating an activation of the flexion-relaxation phenomenon - consistent with previous studies investigating this flexion-relaxation response (Shin et al., 2004).

Trunk kinematic variables have been identified as predictive of low back injury risk (Marras et al., 1993; Marras et al., 1995) and it is therefore useful to quantify changes in these variables as a function of controllable lifting task parameters. Given the strong likelihood for an interaction between the kinematics of the low back and the lower extremities, and the potential for this interaction to be affected by the posture of the lower extremities, the current study sought to quantify this response. The lumbar kinematics data gathered in the current study support the notion that stance width effects trunk motion in much the same way that was demonstrated by Cholewicki et al. (1991) – wider stances led to more upright trunk postures. It could be argued that the reduction in effective load height that comes with a wider stance would be the source of this response. To address this argument that this change in peak sagittal angle is the result of the relative increase in height of the load because of the lowering of the body during the wide stance lift, we conducted some simple pilot work. In this pilot work the change in height of the lifter's center of mass from the narrow to the wide stance was measured. Two subjects then performed a shoulder width stance lift from the ground and from a higher position simulating the load height during the wide stance lift (approximately 1.5-3 cm depending on lifter). The results of this pilot work showed that there was no difference in these peak sagittal angles as a result of this change in load height; therefore the results shown in Figure 3 can be attributed to the change in preferred lifting technique.

There are several limitations to the generalizability of these results that need to be noted. First, the manual materials handling experience of the subject population was limited and variable. The participants were full time college students with varied backgrounds in manual materials handling which may have led to variability in levels of lifting technique maturity and thereby variability in lifting performance/muscle coactivation patterns. Comparing our results with those of the experienced weight-lifters of Cholewicki et al. (1991) is difficult and therefore our results may have under-predicted the significance of the changes in muscle coactivation as a result of stance width. Exploring these effects on established manual materials handlers could have affected these results. A second limitation is the load magnitude used in this study. As noted in the Introduction, most of the exercise science-based studies that did show changes in muscle activation profiles required much higher lifting forces. The 10 kg load may not have been sufficient to elicit stance width-dependent responses. Future research could use increasing loads to identify where these biomechanical responses begin to form. Also of interest for future research is the observation that lifting frequency and duration of lifting are two variables that would likely influence the trunk kinematics results of this study by generating local muscle fatigue, the intensity of which would likely vary as a function of stance width.

5. Conclusion

The findings of the current study have shown that lifting stance width had a significant effect on the lifting kinematics employed but there were no statistically significant differences in the muscle activation levels (low back / lower extremity) as a function of this variable. Wide stance (150% of shoulder width) reduced the peak sagittal angle and peak sagittal plane acceleration during both lifting and lowering motions. Decreasing the peak sagittal angle and peak sagittal acceleration during lifting tasks will lead to decreases in peak moments reducing the risk of injury to structures of the low back. Quantifying the impact of stance width on these important variables may provide insight into workplace design strategies that can reduce risk of low back injury.

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Table 1. MANOVA and Univariate ANOVA results.

Independent Variables	**MANOVA**	**Peak Coronal Angle**	**Peak Sagittal Angle**	**Peak Transverse Angle**	**Peak Coronal Velocity**	**Mean Transverse Velocity**	**Peak Coronal Accel**	**Peak Sagittal Accel**	**Peak Transverse Accel**	**PHRGM**
PLACEMENT (P)	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0012**	**<. 0001***	**<. 0001**	**<. 0001**
HEIGHT (H)	**<.0001**	**<. 0001**	**<. 0001**	**<. 0001***	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**
MASS(M)	<.0001	0.4276	0.3418	0.2061	0.1095	0.2308	0.0571	**<. 0001**	0.395	**<. 0001**
PxH	**<.0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**	**<. 0001**
PxM	0.5851	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HxM	0.7512	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PxHxM	0.9982	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* Simple effect analysis did not indicate significant main effect.

Table 2. Probability of High Risk Group Membership as a function of box MASS, starting HEIGHT, and hand PLACEMENT

		PLACEMENT			
MASS	HEIGHT	Position A	Position B	Position C	Position D
5kg	90cm	22.3	20.3	24.5	24.0
	60cm	28.4	26.5	28.8	28.3
	30cm	28.5	28.0	30.3	29.9
10kg	90cm	31.9	27.5	32.6	32.5
	60cm	36.0	34.6	36.7	36.3
	30cm	36.6	36.6	38.1	38.0

Figure 1. Experimental setup

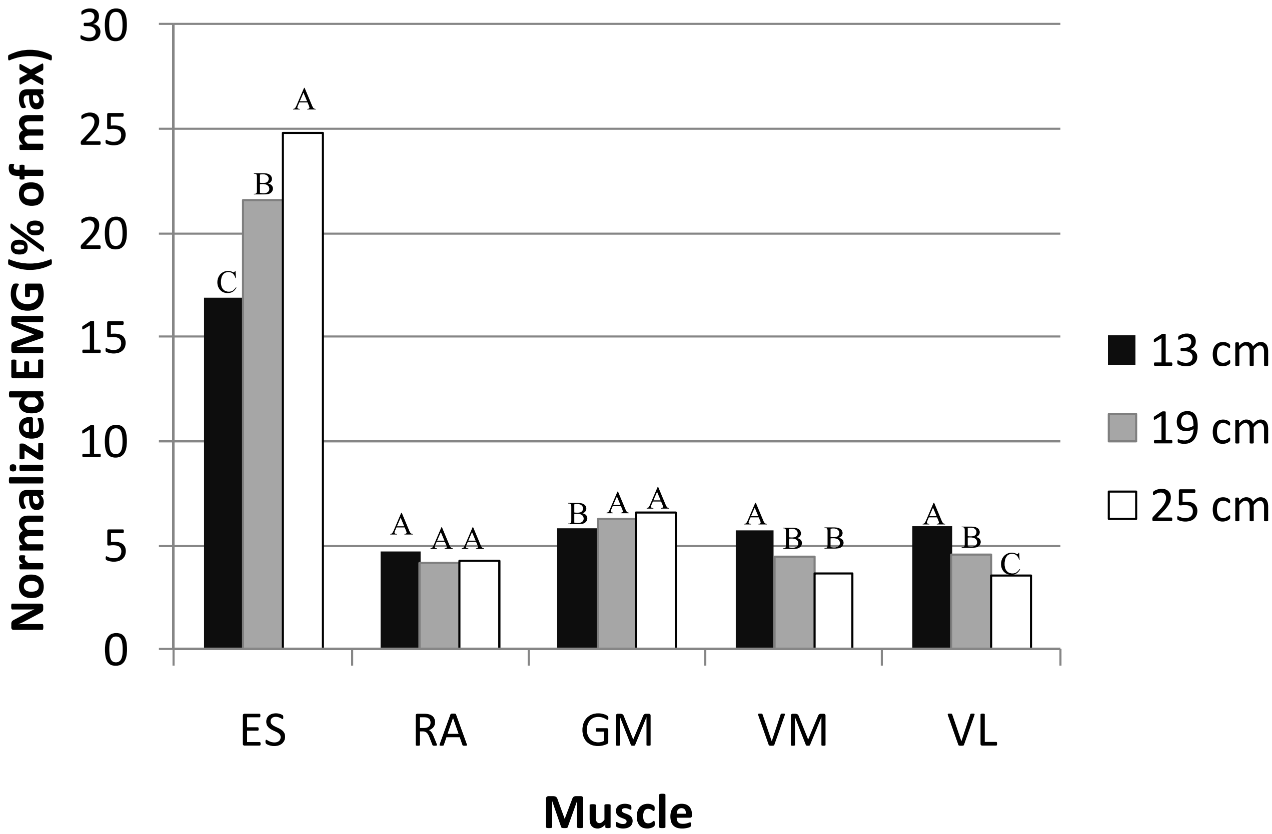

Figure 2. Effect of LOAD HEIGHT on normalized EMG activity (ES Erector Spinae, RA Rectus Abdominis, GM Gluteus Maximus, VM Vastus Medialis, VL Vastus Lateralis).

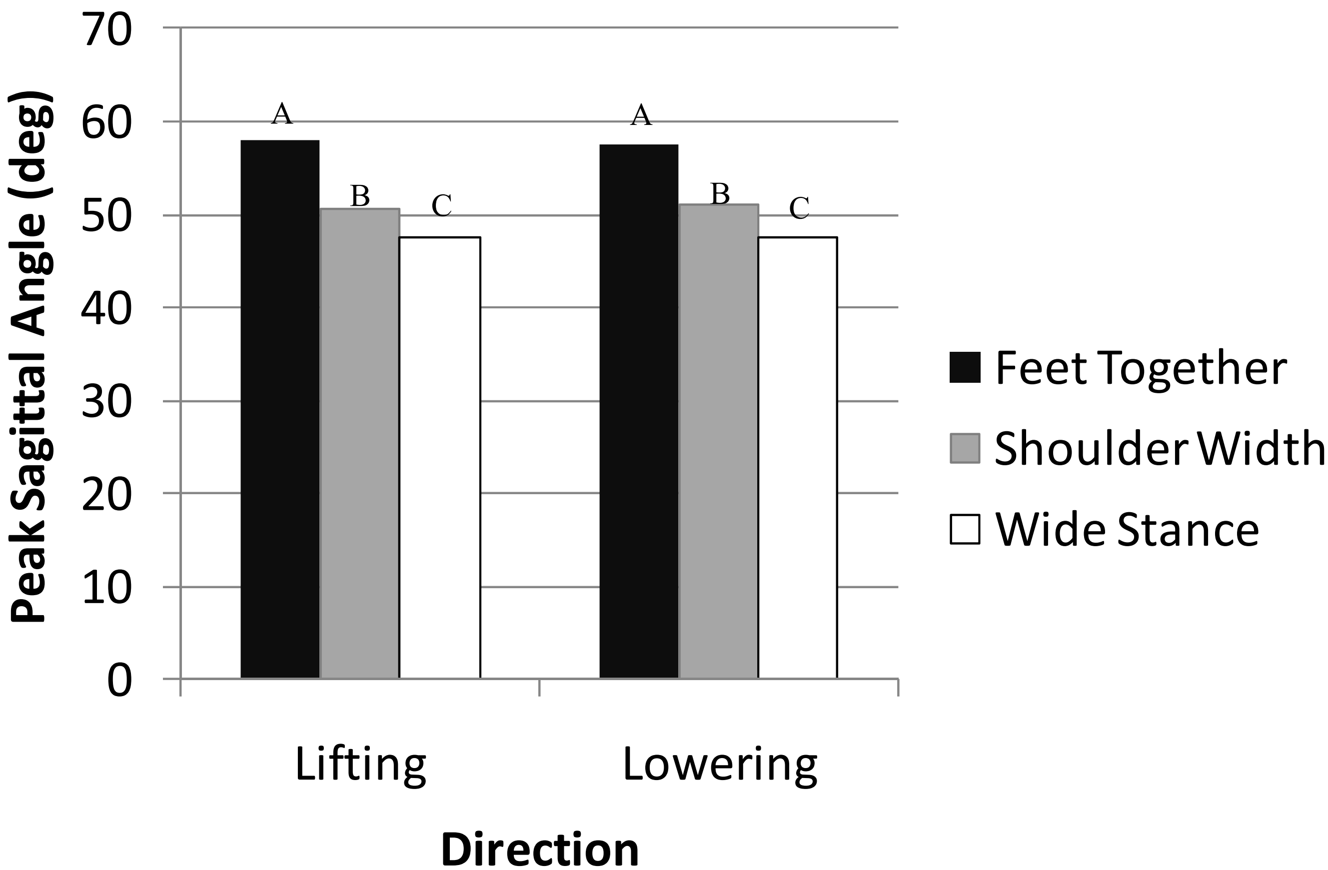

Figure 3. Effect of lifting STANCE WIDTH on peak sagittal angle during both lifting (concentric) and lowering (eccentric) motions.

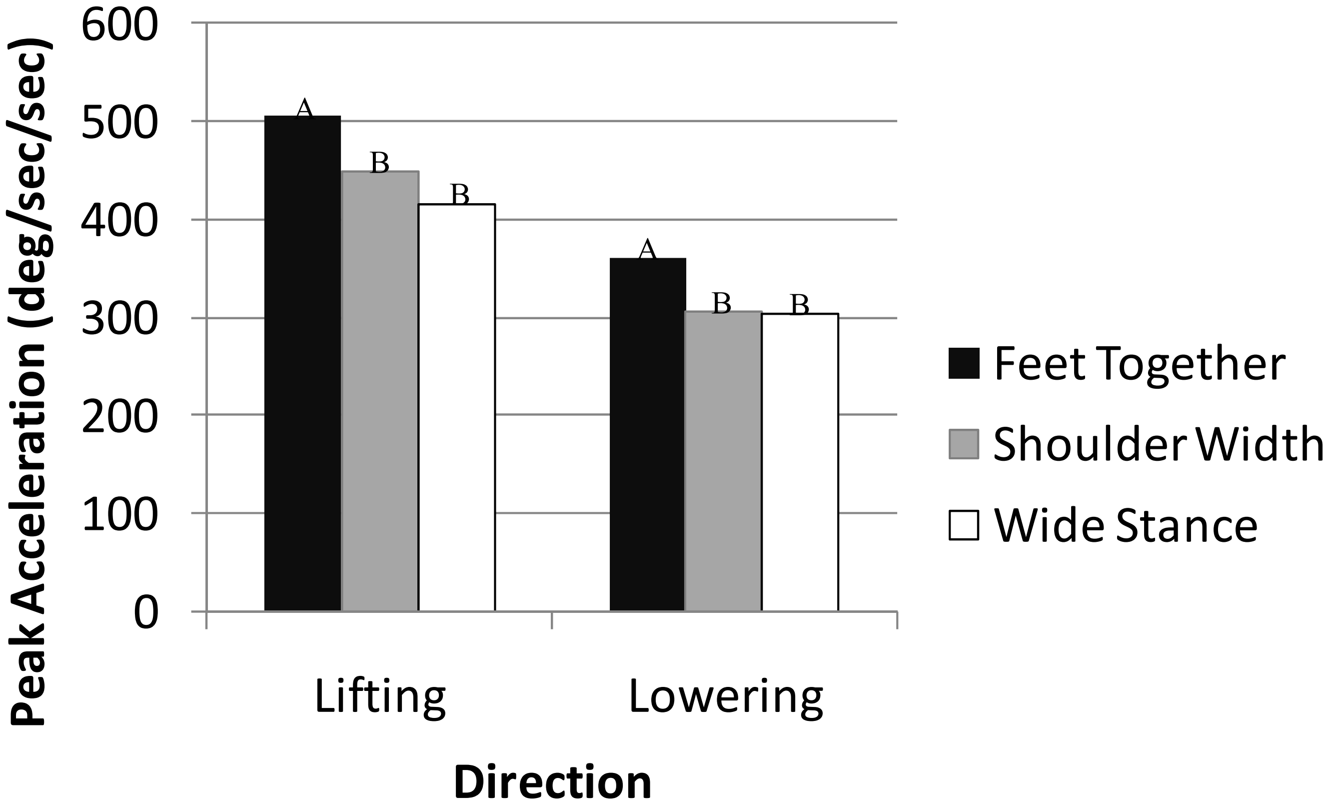

Figure 4. Effect of lifting STANCE WIDTH on peak sagittal acceleration (deceleration) during both lifting (concentric) and lowering (eccentric) motions.