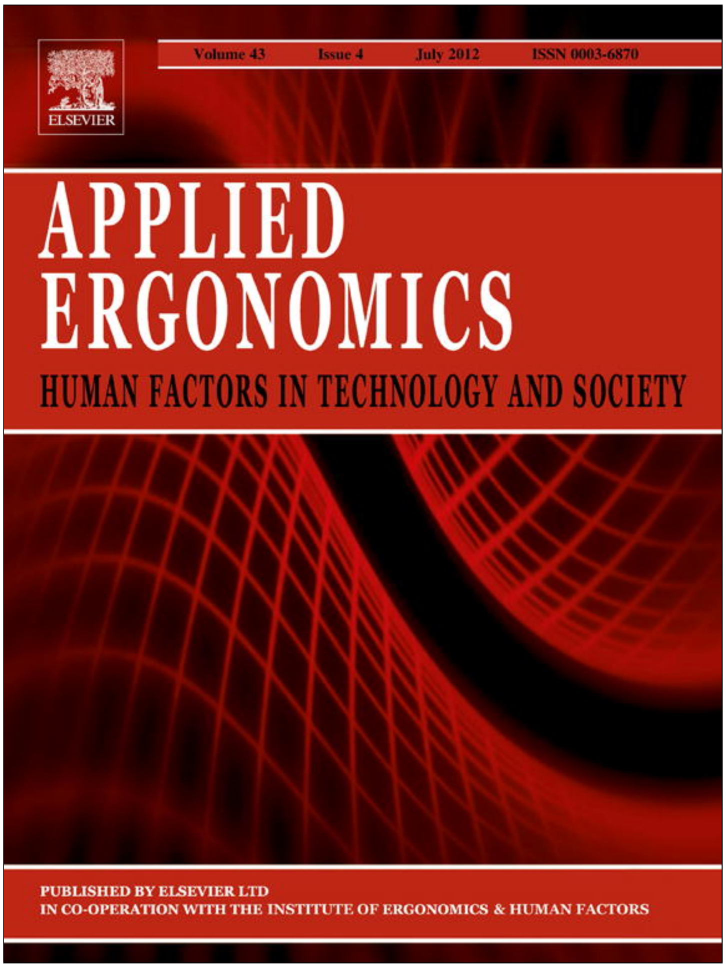
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Musculoskeletal disorder risk during automotive assembly: current vs. seated

Sue A. Ferguson*, William S. Marras, W. Gary Allread, Gregory G. Knapik, Riley E. Splittstoesser

The Ohio State University, Integrated Systems Engineering, Biodynamics Laboratory, Center for Occupational Health in Automotive Manufacturing, 210 Baker Systems, 1971 Neil Avenue, Columbus, OH 43210, USA

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ABSTRACT

Musculoskeletal disorder risk was assessed during automotive assembly processes. The risk associated with current assembly processes was compared to using a cantilever chair intervention. Spine loads and normalized shoulder muscle activity were evaluated during assembly in eight regions of the vehicle. Eight interior cabin regions of the vehicle were classified by reach distance, height from vehicle floor and front to back. The cantilever chair intervention tool was most effective in the far reach regions regardless of the height. In the front far reach regions both spine loads and normalized shoulder muscle activity levels were reduced. In the middle and close reach regions spine loads were reduced, however, shoulder muscle activity was not, thus an additional intervention would be necessary to reduce shoulder risk. In the back far reach region, spine loads were not significantly different between the current and cantilever chair conditions. Thus, the effectiveness of the cantilever chair was dependent on the region of the vehicle.

1. Introduction

Musculoskeletal disorders (MSDs) continue to be a tremendous burden in industry with low back and shoulder disorders being among the most common and costly disorders (NRC, 2001; Dunning et al., 2010). Automotive manufacturing is one of several industries that has a high incidence of MSDs (Ulin and Keyserling, 2004; Punnett, 1999; Landau et al., 2008). One important risk factor for MSDs is force level or load on the joint (Silverstein et al., 1997; Bernard, 1997; Punnett et al., 2004; Fan et al., 2009). Skeletal muscle can generate large internal forces on the joints, tendons and nerve during movement that may lead to MSDs (Cutlip et al., 2009). Surface electromyography (EMG) and EMG-assisted spine loading models have been used to assess internal forces acting on the spine and the risk of low back disorders (Kim and Marras, 1987; Marras and Sommerich, 1991a; McGill and Norman, 1986; Garnder-Morse et al., 1995; Potvin, 2008). Furthermore, EMG of the shoulder muscles has also been used to assess exposure to physical demands in the workplace and subsequent risk of shoulder injury (Lee et al., 1997; Southard et al., 2007; Bao et al., 2009; Porter et al., 2010). Research has shown that EMG activity was correlated with MSD symptoms (Ostensvik et al., 2009). Hence, researchers may assess load on the joint or normalized muscle activity to evaluate the effectiveness of an intervention tool at reducing MSD risk.

One potential intervention in automotive assembly processes is a cantilever beam chair as shown in Fig. 1. Workers would sit in the chair to enter the vehicle, performing assembly processes while sitting in the seat. However, we do not know, from a biomechanical perspective, how much influence using the seated assembly condition would have on reducing musculoskeletal exposure. Thus, the goal of this project was to quantify MSD exposure as a function of the assembly condition (current vs. seated). Specifically, spine and shoulder exposure, two of the most common MSDs (Dunning et al., 2010), were measured via spine loads and normalized shoulder muscle activity levels.

2. Methods

2.1. Approach

Assembly tasks were considered as function of eight regions of the vehicle as illustrated in Fig. 2. All the task regions were in the interior cabin of the vehicle. The regions were based on height and reach distance and include: 1) high height, far reach, back; 2) high height, far reach front; 3) low height, close reach; 4) high height, close reach; 5) low height, far reach; 6) middle height, close reach; 7) middle height, far reach; 8) middle height, middle reach.

2.2. Subjects

Ten subjects participated in the study (eight males and two females, one experienced and one inexperienced female). Five

* Corresponding author. Tel.: +1 614 537 4508; fax: +1 614 292 7852.
E-mail address: ferguson.4@osu.edu (S.A. Ferguson).

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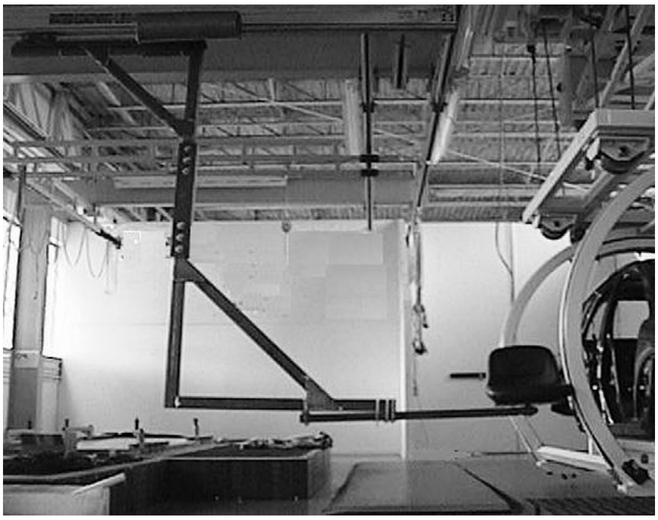

Fig. 1. Cantilever chair.

subjects were experienced auto assembly workers and five were students. The experienced subjects were volunteers from a local assembly plant and all had at least five years experience in automotive assembly. Specifically, the volunteers were recruited from the areas in the plant where tasks in each region were performed. The experienced workers were not experienced with the cantilever chair therefore this group had a practice session using the chair prior to data collection. The student volunteers were given three training sessions on both current and cantilever chair conditions prior to data collection in order to reduce any differences between experienced and inexperienced subjects. The students were required to perform the tasks within the cycle time allotted to workers on the line in order to progress to data collection. The average age was 30.9 (9.69) years. The average (standard deviation) height and weight was 173.23 (6.85) cm and 74.00 (13.15) kg, respectively.

2.3. Experimental design

The independent measure was assembly condition with two levels either the current condition or cantilever chair condition. In regions 1 and 2, the workers climbed in the vehicle and kneeled or sat to perform the current conditions whereas in regions 3–8 the workers leaned in the vehicles to perform the current conditions. The cantilever chair condition the workers sat on the chair and moved his or her feet along the bottom of the vehicle to move into the vehicle. There were nine dependent measures. There were three spine loads including compression, lateral shear and anterior/posterior shear. In addition six shoulder muscle measures were monitored including right and left lateral deltoid, right and left anterior deltoid and right and left supraspinatus.

2.4. Equipment

2.4.1. Cantilever chair

A low cost cantilever chair was fabricated with a seat with lumbar support. The seat turned 180° on the end of the beam. The seat had to enter in the front door of the vehicle. The seat went straight in and out of the vehicle. There were no power controls on the seat or places to place tools. Fig. 3 illustrates the chair in use.

2.4.2. Electromyography

A wired electromyography (EMG) system (Deslsys, Boston, MA) was used to collect muscle activity data. Ten trunk muscles were collected including left and right latissimus dorsi, left and right erector spinae, left and right rectus abdominus, left and right internal oblique, and left and right external oblique (Mirka and Marras, 1993). Trunk muscle activities were used as inputs to calculate spine loads. In addition, shoulder muscle activity was collected on the right and left lateral deltoid, right and left anterior deltoid and right and left supraspinatus (Konard, 2005).

2.4.3. Trunk position

A skin-based goniometer (Sonosens, Friendly Sensors, Jena, Germany) was used to measures trunk posture in all three plane of

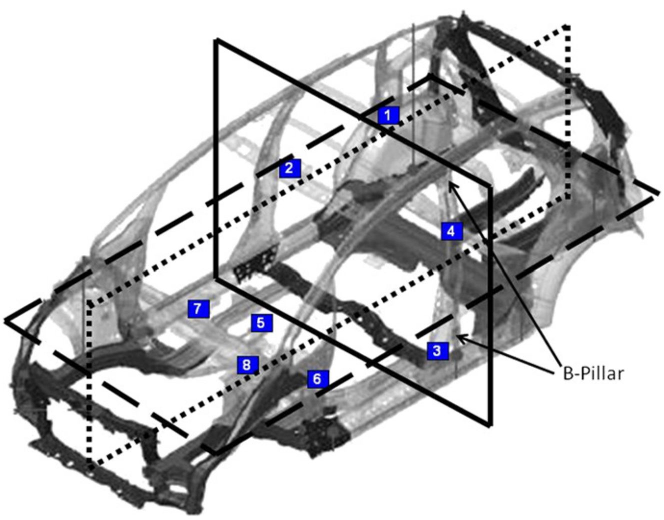

Fig. 2. Regions of vehicle and indication of the B-pillar.

Fig. 3. Cantilever chair in use for assembly task.

the body on all tasks. The sonosens device uses ultrasound to measure distance during skin distraction. Sonosens sensors were placed at L5, L3, and T12 levels on both the right and left sides of spine approximately 6 cm from the midline of the spine. The final sonsens sensor was placed at the level of the iliac crest 2.5 cm inward on the back. In laboratory experiments this set up was found to have the best R^2 values when regressing to the lumbar motion monitor in pilot studies.

In addition, the lumbar motion monitor (LMM) was used to measure trunk posture during calibration trials. A force plate was used to measure moments and forces during calibration trials.

2.5. Procedure

Upon arrival to the testing facility subjects signed the university's internal review board (IRB) consent form. Anthropometric measures were collected including standing height, spine length, trunk circumference, trunk breadth and depth. These anthropometric measures were used as inputs for the spine loading model, which allows for the personalization of the model for each subject. Further details of spine loading model are in Section 2.7. Trunk muscle surface electrodes were placed according to Mirka and Marras (1993) and shoulder muscle electrodes were placed as illustrated in Konrad's *The ABCs of EMG* (Konard, 2005).

Next, subjects performed maximum exertions for each muscle. The trunk muscle maximum exertions were performed first. The subject was strapped in an asymmetric reference frame for these exertions. The maximum exertions were all static. The subject was flexed 30° forward at the waist for the extension maximum. The subject was returned to an upright posture for the remainder of the trunk maximum exertions. There were five maximum static exertions in the upright posture including flexion, left lateral, right lateral, left twist and right twist. The maximum muscle activity from any of these six exertions could be used as the MVC for any trunk muscle. Next shoulder muscle maximum exertions were collected. Several isometric maximum exertions were collected including 1) arm down to side elbow bent 90° exertions outward against asymmetric reference frame bar, 2) arm down to side elbow straight should angle approximately 30° forward exert forward against asymmetric reference frame bar, 3) arm down to side elbow bend 90°, shoulder flexion angle 30° and exert forward against asymmetric reference frame, 4) while sitting shoulder shrug upward, 5) while sitting shoulder shrug upward while experimenter pressed downward, and 6) pulling upward on bar while standing on platform. Exertions 1–3 were performed on both the right and left side whereas exertions 4–6 were performed bilaterally. Shoulder maximum exertions could come from any of these exertions. Exertion 3 posture was selected because it closely represented several of the task postures.

After this, the LMM was placed on the subject. The subject then performed a set of standard lifting conditions while standing on the force plate. Muscle gains (required for the biomechanical model) were set using the standard lifting exertions (Fathallah et al., 1997) in conjunction with an optimization testing scheme (Prahbu, 2005). Next, the Sonosens goniometer was placed on the subject and the subject performed standard flexion extension, side to side, twisting and sit to stand calibration exertions. The lumbar motion monitor was removed and data collection of the trials began. The EMG data was collected at 1000 Hz via hard wire cable using custom laboratory software whereas the goniometer data was collected at 12 Hz.

2.6. Testing

The installation tasks performed for the study included insulator install far and middle reach, bolt tightening far and close reach, seat belt install, shoulder slide install, roof console install, and dome light install. A tool was used in the dominate hand for all tasks except the insulator install task which clipped in place. The task order was completely randomized. The order of the current condition and cantilever chair were counterbalanced. Each task was repeated three times. There were a total of 48 trials. The individual trials ranged from 20 to 45 s depending on the task. All tasks were real assembly tasks simulated in the laboratory for the study. A time marker was used during data collection to indicate when the subject was performing the task. Subjects began and ended each trial standing erect with hands at their sides in order record a neutral reference. The total duration of testing with set up and breaks was approximately 8 h.

2.7. Data analysis

Preliminary data analysis of the calibration exertions while the subject was wearing the LMM and goniometer was performed first. Linear regression models were created from the calibration trials between the LMM and goniometer data to calculate position data in all three planes. A separate regression model was developed for the sagittal, lateral and transverse planes. The R^2 value in each regression model was at least 0.8 in order move on with analysis. The regression equations were then applied to all the trials from each condition to quantify trunk position. Thus, trunk posture was measured with the sonosens goniometer during the trials because the LMM could not be worn while seated.

The EMG signals were low pass filtered at 450 Hz, high pass filtered at 30 Hz, and notch filtered at 60 Hz, rectified and then processed with a 20 ms sliding window. The EMG was then normalized relative to the values collected during the maximum voluntary contractions (MVC). The anthropometric, EMG and kinematic data were imported into an EMG assisted model (Marras and Sommerich, 1991a, b; Granata and Marras, 1993, 1995; Marras and Granata, 1995; Marras and Granata, 1997a, b; Davis et al., 1998; Knapik and Marras, 2009) using MSC.ADAMS software (MSC.Software, 2008). The spine loading model has been shown to be repeatable (Granata et al., 1999). The EMG assisted biomechanical model was used to estimate the spine loads (compression, lateral shear, anterior/posterior shear) resulting from the assembly tasks. The shoulder MVC values were taken from the maximum of any of the six maximum exertions described in Section 2.5.

2.8. Statistical analysis

General linear models were developed (SAS Institute, Cary NC) for each dependent measure to determine if there was a statistically significant difference between the current condition and the cantilever chair condition. Since the goal of the paper was to compare between the cantilever chair and current condition, there was no analysis among the different regions of the vehicle. Tables 1 and 2 list the means (standard deviations), *p*-values and significant difference between the two assembly conditions.

3. Results

Tables 1 and 2 list the means (standard deviations) for each condition (cantilever chair and current) as well as *p*-values indicating statistically significant differences between the two conditions. It should be noted that the spine loading model generates spine loads from L5/S1 to L1/T12 however in the interest of space only one spine level was presented here. The trunk posture and normalized trunk muscle activity levels are inputs into the spine loading model. There were no significant differences among the three trials for each condition on either spine load or shoulder muscle activity measures indicating that these quantitative variables were repeatable.

3.1. High height, far reach, back

There were no significant differences among the spine loads between the two conditions in region 1 as shown in Table 1. Three of the six shoulder muscles had significant differences between the two conditions. However, all three differences showed that the current condition had lower muscle activation levels than the cantilever chair conditions.

3.2. High height, far reach, front

All three spine loads had significant differences between the current condition and cantilever chair as indicated in Table 1. All spine loads show decreases in the cantilever chair compared to the current condition. Furthermore, lateral and anterior/posterior shear dropped by nearly half.

All six shoulder muscles showed significant changes as shown in Table 2. All six muscles had significantly less activity in the cantilever chair compared to the current condition. The three left side muscles all decreased by at least 0.10 of MVC.

3.3. Low height, close reach

Table 1 lists the means (standard deviations) for the spine loads and muscle activity levels. Compression and anterior/posterior shear loads were significantly different whereas lateral shear had no change between the two conditions. Compression decreased by nearly 300 N in the cantilever chair compared to the current condition. Anterior/Posterior shear force decreased from 760 to 580 N. Only one of the six shoulder muscles significantly changed between the two conditions as shown in Table 2. The left anterior deltoid muscle activity significantly increased in the cantilever chair compared to the current condition. Thus, spine load decreased in this region but shoulder muscle activity increased.

3.4. High height, close reach

All three spine load measures changed significantly between the two conditions as indicated in Table 1. Compression decreased approximately 300 N. Lateral shear decreased by nearly half and anterior/posterior shear force decreased from 641 N to 452 N.

Shoulder muscle activity results indicate that the left arm muscle activity changed significantly whereas the right arm muscle activity did not change. All three left arm muscles had significantly greater activity in the cantilever chair compared to the current condition. Thus spine loads decrease but shoulder muscle activity on the left side significantly increased.

3.5. Low height, far reach

Table 1 indicates that all three spine loads changed significantly between the cantilever chair and current condition in region 5 (low height, far reach). Compression decreased by approximately 600 N. Lateral shear decreased by nearly half and anterior/posterior shear roughly 300 N.

Three of the six shoulder muscles changed significantly between the two conditions as indicated in Table 2. Both the left and right anterior deltoid muscle activity decreased significantly. The left lateral deltoid muscle activity decreased from 0.42 to 0.13 of MVC.

3.6. Middle height, close reach

Two of the three spine load measures significantly changed between conditions as indicated in Table 1. Compression decreased significantly in the cantilever chair compared to the current condition. Anterior/posterior shear also decreased significantly in the cantilever chair condition. There were no significant changes in the shoulder muscle activity levels between the two conditions.

3.7. Middle height, far reach

All three spine load measures changed significantly in region 7 (middle height, far reach) as shown in Table 1. Compression

Table 1
Spine load means (standard deviations) for 10 subjects by region and assembly condition.

Region	Dependent measures	Condition: Current	Condition: Cantilever chair	*P*-values
1: High height, far reach, back of vehicle	Compression (L5/S1)	1142 (402)	1288 (472)	0.292
	Lateral shear (L2/L3)	207 (147)	227 (153)	0.337
	Anterior/posterior shear (L2/L3)	488 (190)	545 (230)	0.679
2: High height, far reach, front of vehicle	Compression (L5/S1)	1238 (468)	805 (186)	0.005[a]
	Lateral shear (L2/L3)	327 (228)	172 (97)	0.018[a]
	Anterior/posterior shear (L2/L3)	479 (225)	234 (164)	0.003[a]
3: Low height, close reach	Compression (L5/S1)	1618 (354)	1379 (414)	0.028[a]
	Lateral shear (L2/L3)	394 (214)	318 (203)	0.411
	Anterior/posterior shear (L2/L3)	761 (228)	580 (298)	0.018[a]
4: High height, close reach	Compression (L5/S1)	1396 (231)	1081 (259)	0.001[a]
	Lateral shear (L2/L3)	326 (190)	158 (95)	0.007[a]
	Anterior/posterior shear (L2/L3)	641 (134)	452 (151)	0.008[a]
5: Low height, far reach	Compression (L5/S1)	1696 (479)	1096 (257)	0.004[a]
	Lateral shear (L2/L3)	277 (228)	140 (97)	0.035[a]
	Anterior/posterior shear (L2/L3)	698 (343)	403 (213)	0.009[a]
6: Middle height, close reach	Compression (L5/S1)	1268 (343)	907 (282)	0.001[a]
	Lateral shear (L2/L3)	152 (113)	104 (68)	0.100
	Anterior/posterior shear (L2/L3)	516 (328)	327 (167)	0.031[a]
7: Middle height, far reach	Compression (L5/S1)	1633 (556)	1004 (240)	0.004[a]
	Lateral shear (L2/L3)	240 (154)	126 (108)	0.011[a]
	Anterior/posterior shear (L2/L3)	774 (342)	350 (129)	0.003[a]
8: Middle height, middle reach	Compression (L5/S1)	1398 (308)	1004 (301)	0.016[a]
	Lateral shear (L2/L3)	228 (128)	146 (137)	0.044[a]
	Anterior/posterior shear (L2/L3)	607 (211)	321 (196)	0.003[a]

[a] Indicates statistical significance at alpha = 0.05.

Table 2
Shoulder muscle (normalized to MVC) activity means (standard deviation) for 10 subjects by region and assembly condition.

Region	Dependent measures	Condition		*P*-values
		Current	Cantilever chair	
1: High height, far reach, back of vehicle	Right Lateral Deltoid	0.20 (0.11)	0.24 (0.12)	0.002[a]
	Left Lateral Deltoid	0.26 (0.19)	0.32 (0.21)	0.104
	Right Anterior Deltoid	0.40 (0.15)	0.45 (0.13)	0.119
	Left Anterior Deltoid	0.34 (0.15)	0.46 (0.25)	0.018[a]
	Right Supraspinatus	0.26 (0.13)	0.30 (0.16)	0.049[a]
	Left Supraspinatus	0.32 (0.14)	0.37 (0.21)	0.085
2: High height, far reach, front of vehicle	Right Lateral Deltoid	0.16 (0.11)	0.12 (0.10)	0.002[a]
	Left Lateral Deltoid	0.32 (0.21)	0.21 (0.21)	0.005[a]
	Right Anterior Deltoid	0.47 (0.21)	0.29 (0.15)	0.028[a]
	Left Anterior Deltoid	0.40 (0.19)	0.31 (0.19)	0.039[a]
	Right Supraspinatus	0.32 (0.22)	0.16 (0.09)	0.006[a]
	Left Supraspinatus	0.36 (0.15)	0.26 (0.19)	0.016[a]
3: Low height, close reach	Right Lateral Deltoid	0.20 (0.12)	0.13 (0.05)	0.053
	Left Lateral Deltoid	0.32 (0.18)	0.39 (0.25)	0.264
	Right Anterior Deltoid	0.20 (0.09)	0.19 (0.09)	0.776
	Left Anterior Deltoid	0.14 (0.19)	0.26 (0.20)	0.032[a]
	Right Supraspinatus	0.33 (0.22)	0.19 (0.15)	0.084
	Left Supraspinatus	0.32 (0.19)	0.27 (0.16)	0.278
4: High height, close reach	Right Lateral Deltoid	0.26 (0.21)	0.22 (0.21)	0.160
	Left Lateral Deltoid	0.22 (0.22)	0.46 (0.42)	0.017[a]
	Right Anterior Deltoid	0.33 (0.16)	0.29 (0.10)	0.346
	Left Anterior Deltoid	0.22 (0.20)	0.31 (0.17)	0.007[a]
	Right Supraspinatus	0.31 (0.23)	0.27 (0.12)	0.539
	Left Supraspinatus	0.24 (0.19)	0.37 (0.16)	0.020[a]
5: Low height, far reach	Right Lateral Deltoid	0.18 (0.15)	0.11 (0.06)	0.077
	Left Lateral Deltoid	0.42 (0.22)	0.13 (0.16)	0.002[a]
	Right Anterior Deltoid	0.22 (0.12)	0.15 (0.10)	0.044[a]
	Left Anterior Deltoid	0.35 (0.24)	0.17 (0.15)	0.025[a]
	Right Supraspinatus	0.24 (0.18)	0.22 (0.15)	0.653
	Left Supraspinatus	0.30 (0.18)	0.19 (0.16)	0.067
6: Middle height, close reach	Right Lateral Deltoid	0.12 (0.18)	0.12 (0.09)	0.963
	Left Lateral Deltoid	0.16 (0.23)	0.13 (0.15)	0.478
	Right Anterior Deltoid	0.08 (0.08)	0.07 (0.05)	0.694
	Left Anterior Deltoid	0.17 (0.21)	0.25 (0.20)	0.127
	Right Supraspinatus	0.15 (0.13)	0.18 (0.12)	0.232
	Left Supraspinatus	0.22 (0.19)	0.27 (0.18)	0.296
7: Middle height, far reach	Right Lateral Deltoid	0.25 (0.25)	0.25 (0.12)	0.931
	Left Lateral Deltoid	0.44 (0.24)	0.24 (0.27)	0.011[a]
	Right Anterior Deltoid	0.26 (0.14)	0.24 (0.15)	0.925
	Left Anterior Deltoid	0.37 (0.21)	0.24 (0.18)	0.108
	Right Supraspinatus	0.31 (0.23)	0.21 (0.13)	0.097
	Left Supraspinatus	0.34 (0.21)	0.25 (0.18)	0.091
8: Middle height, middle reach	Right Lateral Deltoid	0.22 (0.15)	0.27 (0.17)	0.420
	Left Lateral Deltoid	0.25 (0.21)	0.23 (0.22)	0.881
	Right Anterior Deltoid	0.28 (0.21)	0.38 (0.21)	0.026[a]
	Left Anterior Deltoid	0.43 (0.25)	0.36 (0.28)	0.344
	Right Supraspinatus	0.20 (0.14)	0.19 (0.13)	0.998
	Left Supraspinatus	0.27 (0.20)	0.28 (0.22)	0.563

[a] Indicates statistical significance at alpha = 0.05.

decreased more than 600 N in the cantilever chair compared to the current condition. Anterior/posterior shear decreased from 774 N to 349 N and lateral shear decreased by nearly half. Only one shoulder muscle changed significantly between the two conditions. The left lateral deltoid decreased by 0.2 of MVC in the cantilever chair compared to the current condition.

3.8. *Middle height, middle reach*

All three spine loads measures decreased significantly in the cantilever chair condition compared to the current condition as indicated in Table 1. Only the right anterior deltoid muscle was significantly influenced by the condition. Right anterior deltoid muscle activity increased in the cantilever chair condition compared to the current condition. Thus spine loads decrease with the cantilever chair but shoulder muscle activity increased in this region.

4. Discussion

Table 3 summarizes the results across all regions. Table 3 shows that spine loads were less in the cantilever chair condition compared to the current condition in seven of the eight regions. The decrease in spine loading was created by reduced muscle co-activation levels in the cantilever chair condition compared to the current condition. The spine load rating and shoulder muscle rating columns in Table 3 indicate the effectiveness of the cantilever chair at reducing exposure in that region. A "+" indicates that exposure was reduced in that region whereas a "−" indicates exposure increased with the cantilever chair in that region. The table indicates that the shoulder muscle activity results were more mixed than the spine loads. Three regions show less muscle activity in the cantilever chair compared to the current condition whereas four regions had greater muscle activity in the cantilever chair compared to the current condition. The three regions with less shoulder muscle activity in the cantilever chair condition were all

Table 3
Summary of results for spine loads and shoulder muscle activity by region.

Region	Spine loads	Spine load rating	Shoulder muscle activity	Shoulder muscle rating
High height, far reach, back	C. Chair = Current	0	C. Chair > Current	−
High height, far reach, front	C. Chair < Current	+	C. Chair < Current	+
Low height, close reach	C. Chair < Current	+	C. Chair > Current	−
High height, close reach	C. Chair < Current	+	C. Chair > Current	−
Low height, far reach	C. Chair < Current	+	C. Chair < Current	+
Middle height, close reach	C. Chair < Current	+	C. Chair = Current	0
Middle height, far reach	C. Chair < Current	+	C. Chair < Current	+
Middle height, middle reach	C. Chair < Current	+	C. Chair > Current	−

C. Chair = cantilever chair condition, "+" indicates cantilever chair reduced exposure compared to current condition, "0" indicates cantilever chair had equal exposure to current condition, "−" indicates cantilever chair had greater exposure than current condition.

associated with far reach regions. Thus, for the shoulder the cantilever chair was most effective in the far reach regions.

Fig. 4, a top view of the vehicle, illustrates the effectiveness of the cantilever chair intervention tool by region. The figure indicates that the front far reach regions were good regions for implementation of the cantilever chair regardless of the height of the task. In other words for all three heights (low, medium and high) the cantilever chair will reduce both shoulder and low back exposure in the far reach region. In the close and middle reach regions Fig. 4 indicates "ok" which means the spine loads are reduced but another intervention would be necessary to reduce shoulder muscle activity. The high height, far reach, back region resulted in increased shoulder muscle activity and no change in spine load. Thus, this region would not be a recommended area to implement the cantilever chair intervention as indicated in Fig. 4.

It has been hypothesized that the difference between the high height front and back results may be due to the design of the chair. The cantilever chair can only enter the vehicle from the front door and go back in the vehicle as far as the b-pillar (shown in Fig. 2). In the cantilever chair condition, the worker had to reach from the chair to perform the assembly task whereas in the current condition the worker could move directly under the process. Thus, it was theorized that the reach requirement from the chair created the increased shoulder muscle activity during this task. Furthermore, the spine loads were the same between the two conditions therefore it was theorized that the trunk muscle activity needed to stabilize the trunk in the current condition was approximately the same as that required during reaching from the seat to perform the task. The spine loads were the same between the two conditions and the shoulder muscle activity was greater in the cantilever chair resulting an ineffective intervention tool in the back high height region.

The results of this study can be compared to known risk values for spine loads. The compressive loads were well below 6400 N maximum permissible limit and 3400 N action limit. However, given the highly repetitive nature of the tasks it is essential that the loads be well below the limits. In shear loads, the tolerances are between 750 N and 1000 N (Marras, 2008; McGill, 2002). None of the current conditions have shear loads exceeding 1000 N. Two of the current conditions did exceed 750 N including 1) middle height, far reach region and 2) low height, close reach region. In both cases the cantilever chair intervention reduced the anterior/posterior shear load below the 750 N threshold. The lateral shear load was well below the thresholds in all regions.

The results of this study quantify the magnitude or amplitude of exposure. Hagg et al. (2000) suggest that exposure must also provide a duration as well as frequency. Thus in comparing the current vs. cantilever chair these issues should be considered. The duration of the exposure to the assembly tasks would be the same regardless of the current or cantilever chair. The workers in the plant rotate every 2 h this would remain the same regardless of the assembly condition. Furthermore, the repetition per 2 h cycle would remain the same regardless of the assembly condition. Thus, the magnitude of exposure is going to be the only aspect of the exposure measure to change between the two assembly conditions. In addition to reducing the magnitude of exposure in some regions, the cantilever chair eliminated climbing in and out the vehicle. By eliminating the in/out of the vehicle this may reduce the number of acute injuries such as cuts and scrapes from sharp metal, slips and falls.

The results of this study show that ergonomists must exercise care when implementing interventions. An intervention may reduce the risk of injury to one joint but increase the risk to another joint. Injury statistics may show that there is a problem in a facility that needs to be addressed but while providing a solution to one problem ergonomists must be careful not to create another problem. The results of this study provide valuable insight as to which regions of the vehicle reduce the risk of both back and shoulder risk and which regions require additional interventions to the shoulder. It is hypothesized that the results may be generalized to all tasks in the regions.

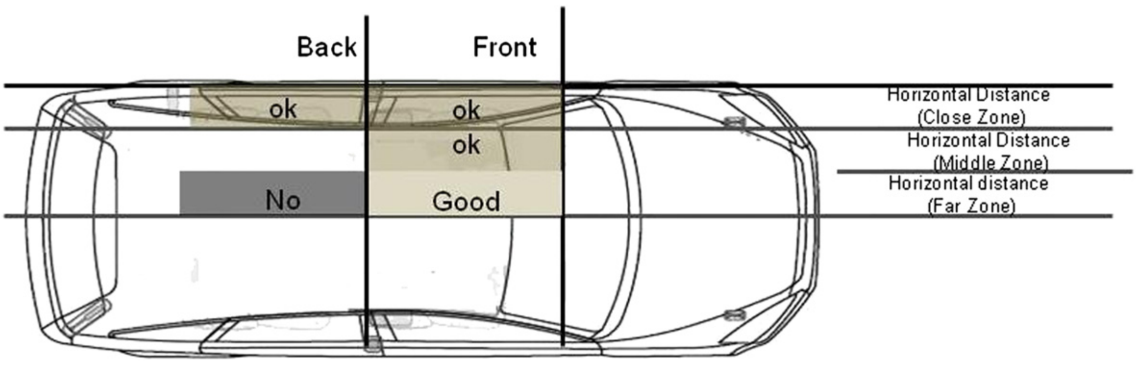

Fig. 4. Effectiveness of cantilever chair intervention by regions.

The cantilever chair is an inexpensive intervention tool. It is most effective in the front far reach region of the vehicle regardless of height. Thus to implement the cantilever chair most effectively in an auto assembly plant may require rebalancing the line after installing the chair in order to have enough tasks performed efficiently. It is hypothesized that just a few cantilever chairs on strategic tasks would reduce the risk of low back and shoulder MSDs in an automotive assembly plant. In addition to reducing MSDs the cantilever chair may reduce the acute injuries and abrasions suffered during entering and exiting the vehicle in the current condition. Another key component of successful implementation would be operator preference or acceptance of the cantilever chair. Unfortunately, worker preference was not measured in the current study.

In summary, we can develop guidelines or rules for implementation of the cantilever chair intervention based on the results of the study. A "good" region of the vehicle to implement the cantilever chair intervention is one where both spine loads and normalized shoulder muscle activity levels were reduced. A region where spine loads were reduce but shoulder muscle activity either increased or did not change would be "ok" to implement the cantilever chair however other interventions may be necessary to reduce the risk of shoulder injury. A "bad" region to implement the cantilever chair intervention would be one where spine loads did not change compared to the current condition and normalized shoulder muscle activity increased.

5. Limitations

The first limitation was the small sample size. The second limitation was that only one task was examined in each region of the vehicle. The task was selected to be a representative sample form that region of the vehicle however there might be some difference in tasks within that region of the vehicle. It would be too expensive to test every task in every region of the vehicle to determine the effectiveness of the cantilever chair intervention. There are also may be some difference among vehicle and again it would too expensive to test the tool on all vehicles. It is hypothesized that these results applicable to all tasks in a given region and variation due to vehicle would be small. Only shoulder muscle activity and spine loads were examined in this study of injury risk. Finely, exposure of shoulder posture as well as wrist, neck and lower extremity may be influenced by the cantilever chair compared to the current condition but was not examined in this study. Shoulder posture was not measured in this study due to the equipment interfering with the seated posture.

6. Conclusions

The cantilever chair was a good intervention in the front far reach region regardless of height, because it reduced spine loads and reduced normalized shoulder muscle activity. In the middle and close reach distance regions the cantilever chair caused spine loads to be reduced however other interventions would be necessary to reduce normalize shoulder muscle activity. Finally, in the back region of the vehicle the cantilever chair caused no change in spine loads and increased shoulder muscle activity, therefore it was not an effective intervention tool in this region.

Statement of relevance

Musculoskeletal disorder risk was examined during the current assembly processes compared to that using a cantilever chair intervention tool. The results indicate in which regions of the vehicle the cantilever chair intervention tool was most effective at reducing the risk of low back and shoulder disorders.

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References

Bao, S., Spielholtz, P., Howard, N., Silvertein, B., 2009. Force measurement in field ergonomics research and application. Int. J. Ind. Ergon. 39, 333–340.

Bernard, B., 1997. Musculoskeletal Disorders and Workplace Factors. A Critical Review of Epidemiologic Evidence for Work-related Musculoskeletal Disorder of the Neck, Upper Extremity, and Low Back. DHHS (NIOSH) Publication #97–141. US Department of Health and Human Services (NIOSH), Cincinnati, OH.

Cutlip, R.G., Baker, B.A., Hollander, M., Ensey, J., 2009. Injury and adaptive mechanisms in skeletal muscle. J. Electromyogr. Kinesiol. 19, 358–372.

Davis, K.G., Marras, W.S., Waters, T.R., 1998. The evaluation of spinal loads during lowering and lifting. Clin. Biomech. 13, 141–152.

Dunning, K.K., Davis, K.G., Cook, C., Kotowski, S.E., Hamrick, C., Jewell, G., Lockey, J., 2010. Costs by industry and diagnosis among musculoskeletal claims in a state workers compensation system: 1999–2004. Am. J. Ind. Med. 53, 276–284.

Fan, Z.J., Silverstein, B.A., Bao, S., Bonauto, D.K., Howard, N.L., Spielholz, P.O., Smith, C.K., Plissar, N.L., Viikari-Juntura, E., 2009. Quantitative exposure-response relations between physical workload and prevalence of lateral epicondylitis in a working population. Am. J. Ind. Med. 52, 479–490.

Fathallah, F.A., Marras, W.S., Parnianpour, M., Granata, K.P., 1997. A method for measuring external spinal loads during unconstrained free-dynamic lifting. J. Biomech. 30, 975–978.

Gardner-Morse, M., Stokes, I.A., Laible, J.P., 1995. Role of muscles in lumbar spine stability in maximum entension efforts. J. Orthop. Res. 13 (5), 802–808.

Granata, K.P., Marras, W.S., 1993. An EMG-assisted model of loads on the lumbar spine during asymmetric trunk extensions. J. Biomech. 26, 1429–1438.

Granata, K.P., Marras, W.S., 1995. An EMG-assisted model of trunk loading during free-dynamic lifting. J. Biomech. 28, 1309–1317.

Granata, K.P., Marras, W.S., Davis, K.G., 1999. Variation in spinal load and trunk dynamics during repeated lifting. Clin. Biomech. 14, 367–375.

Hagg, G.M., Luttman, A., Jager, M., 2000. Methodologies for evaluating electromyographic field data in ergonomics. J. Electromyogr. Kinesiol. 10, 301–312.

Kim, J.Y., Marras, W.S., 1987. Quantitative trunk muscle electromyography during lifting at different speeds. Int. J. Ind. Ergon. 1, 219–229.

Knapik, G.G., Marras, W.S., 2009. Spine loading at different lumbar levels during pushing and pulling. Ergonomics 52, 60–70.

Konard, P., 2005. The ABC of EMG a Practical Introduction to Kinesiological Electromyography. Version 1.0. Noraxon INC, USA.

Landau, K., Rademacher, H., Meschke, H., Winter, G., Schaub, K., Grasmueck, M., Moelbert, I., Sommer, M., Schulze, J., 2008. Musculoskeletal disorders in assembly jobs in the automotive industry with special reference to age management aspects. Int. J. Ind. Ergon. 28, 561–576.

Lee, C.C., Nelson, J.E., Davis, K.D., Marras, W.S., 1997. An ergonomic comparison of industrial spray paint guns. Int. J. Ind. Ergon. 19, 425–426.

Marras, W.S., 2008. The Working Back a Systems View. John Wiley & Sons Inc, Hoboken.

Marras, W.S., Granata, K.P., 1995. A biomechanical assessment and model of axial twisting in the thoracolumbar spine. Spine 20, 1440–1451.

Marras, W.S., Granata, K.P., 1997a. The development of an EMG-assisted model to assess spine loading during whole-body free-dynamic lifting. J. Electromyogr. Kinesiol. 7, 259–268.

Marras, W.S., Granata, K.P., 1997b. Spine loading during trunk lateral bending motions. J. Biomech. 30, 697–703.

Marras, W.S., Sommerich, C.M., 1991a. A three-dimensional motion model of loads on the lumbar spine: I. Model structure. Hum. Factors 33, 123–137.

Marras, W.S., Sommerich, C.M., 1991b. A three-dimensional motion model of loads on the lumbar spine: II. Model validation. Hum. Factors 33, 139–149.

McGill, S., 2002. Low Back Disorders Evidence-Based Prevention and Rehabilitation. Human Kinetics, Champaign.

McGill, S., Norman, R.W., 1986. Partitioning of the L4–L5 dynamic moment into disc, ligaments, and muscular components during lifting. Spine 11 (7), 666–677.

Mirka, G.A., Marras, W.S., 1993. A stochastic model of trunk muscle coactivation during trunk bending. Spine 18, 1396–1409.

MSC Software, 2008. MD Adams R3 Release Guide. MSC Software Corportation, Santa Ana.

National Research Council (NRC), 2001. Musculoskeletal Disorders and the Workplace Low Back and Upper Extremities. National Academy Press, Washington DC.

Ostensvik, T., Veiersted, K.B., Nilson, P., 2009. Association between numbers of long periods with sustained low-level trapezius muscle activity and neck pain. Ergonomics 52 (12), 1556–1567.

Porter, W., Gallagher, S., Torma-Krajewski, J., 2010. Analysis of applied forces and electromyography of back and shoulder muscles when performing a simulated hand scaling task. Appl. Ergon. 41, 411–416.

Potvin, J.R., 2008. Occupational spine biomechanics: a journey to the spinal frontier. J. Electromyogr. Kinesiol. 18 (6), 891–899.
Prahbu, J., 2005. An Investigation on the Use of Optimization to Determine the Individual Muscle Gains in a Multiple Muscle Model. Department of Industrial and Systems Engineering Vol. MS, The Ohio State University, Columbus, OH.
Punnett, L., 1999. The cost of work-related musculoskeletal disorders in automotive manufacturing. New Solutions: J. Environ. Occ. Health 9 (4), 403–426.
Punnett, L., Gold, J., Katz, J., Gore, R., Wegman, D., 2004. Ergonomic stressors and upper extremity musculoskeletal disorders in automobile manufacturing: a one year follow up study. Occup. Environ. Med. 61 (8), 668–674.
SAS Institute, 1990. SAS/STAT User's Guide, Version 6, fourth ed. SAS Institute, Inc, Cary NC.
Silverstein, B.A., Stetson, D.S., Keyserling, W.M., Fine, L.J., 1997. Work-related musculoskeletal disorders: comparison of data sources for surveillance. Am. J. Ind. Med. 31, 600–608.
Southard, S.A., Freeman, J.H., Drum, J., Mirka, G.A., 2007. Ergonomic interventions for the reduction of back and shoulder biomechanical loading when weighing calves. Int. J. Ind. Ergon. 37, 103–110.
Ulin, S.S., Keyserling, W.M., 2004. Case studies of ergonomic interventions in automobile parts distribution operations. J. Occup. Rehabil. 14, 307–326.