ERGONOMICS, 15 SEPTEMBER, 2004, VOL. 47, NO. 11, 1226–1237

Taylor & Francis healthsciences

The influence of individual low back health status on workplace trunk kinematics and risk of low back disorder

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Keywords: Industrial ergonomics; Low-back disorder risk.

A case-control study was conducted to determine whether or not kinematic-based low back disorder risk measurement (Marras *et al*. 1993) of the job was significantly different for those workers suffering from recent low back injuries compared to asymptomatic controls. Two hundred low back injured workers returning to full duty work and 200 asymptomatic controls were evaluated while performing the same job. There were no statistically significant differences between the two groups on any trunk motion measures or workplace measures. Therefore, job design is dictating the kinematic motions of the torso and not the worker's low back health. In addition, there was not a significant difference in job risk estimates using the lumbar motion monitor risk model. The mean risk (and standard deviation) for the low back injured group and the asymptomatic controls was 0.502 (0.178) and 0.501 (0.193), respectively. This study suggests that trunk kinematics and subsequent risk estimates are dictated primarily by job design and not influenced by the low back health status of the worker.

1. Introduction

Risk factors for occupational low back disorders have been classified into physical job demand factors, psychosocial factors and individual factors (NRC 2001). Physical job demand risk factors include bending and twisting (Saraste and Hultman 1987, Riihimaki *et al*. 1989, Burdorf *et al*. 1991, Punnett *et al*. 1991, Xu *et al*. 1997, Josephson and Vingard 1998), and frequent lifting (Nuwayhid *et al*. 1993, Magnusson *et al*. 1996 Ory *et al*. 1997, Kraus *et al*. 1997, Alcouffe *et al*. 1999, Gardner *et al*. 1999) as well as other factors. Risk evaluation techniques to measure bending, twisting and lifting vary; however, the National Research Council (NRC 2001) stated that the most effective models for predicting low back disorder risk were those models that considered trunk kinematics when performing work tasks. Direct measurement of worker trunk kinematics may provide the best measure for prediction models; however it is unknown whether the model results may be influenced by individual risk factors such as the worker's low back health status.

One risk assessment tool that provides a direct measurement of low back trunk kinematics and resulting workplace risk of low back disorder is the lumbar motion monitor (LMM). The LMM risk assessment model quantifies the risk of high risk group membership for low back disorder using a combination of trunk kinematics and workplace measures (Marras *et al*. 1993). The workplace measures consist of lift

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Ergonomics ISSN 0014-0139 print/ISSN 1366-5847 online
http://www.tandf.co.uk/journals
DOI: 10.1080/00140130410001712636

rate and moment and the trunk motion measures include sagittal flexion, lateral velocity and twisting velocity, which may be influenced by individual differences in how workers move their trunks. Clinical studies have shown that those with low back disorders move significantly slower than asymptomatic controls (McIntyre *et al*. 1991, Masset and Malchaire 1994, Marras *et al*. 1995, 1999). Hence, one might hypothesize that the LMM risk estimates could be influenced by whether or not a worker has had a recent low back disorder.

The objective of this study was to quantify the risk of high risk group membership for low back disorder (risk) using the LMM risk model on individuals with low back pain as well as asymptomatic workers. The first goal was to compare trunk motion measures and job risk between an individual with low back pain and without low back pain to determine whether or not low back status influences the LMM risk assessment. The second goal was to quantify the extent to which status influences LMM risk assessment.

2. Methods

2.1. *Approach*

This study performed ergonomic assessments on a variety of repetitive industrial jobs using the LMM risk model with two workers. The first worker had a recent low back injury which resulted in a medical visit and a second worker had no history of low back injury. Using this approach an evaluation of the differences in trunk motions between the two workers was made as a function of job features to determine whether or not these differences influenced the risk assessments when using the LMM risk model.

2.2. *Industry cooperation*

Over 40 manufacturing facilities in the Midwest USA participated in the study. These manufacturing facilities included automobile and truck assembly, automotive parts assembly, food processing, rubber manufacturing, printing, glass production and metal processing. Most of the jobs were line-paced (66%), some were machine paced (22%), and others were self-paced by the operator (11%).

The inclusion criteria for the study were explained to a company representative. The company representative then examined the medical and/or injury records for potential candidates. The potential candidates were asked to participate in the study by the company representative. If the candidate agreed to participate the research team scheduled a day to visit the plant. If the candidate refused to participate the researchers had no information on the candidate. In addition, all injuries were considered work-related low back injuries.

2.3. *Subjects*

Two hundred workers that reported to medical or first aid with low back pain within the past 3 months participated in the study. The inclusion criteria for low back injured worker included (1) time away from his or her regular duty job due to work-related low back pain, and (2) the worker sought medical attention at the plant medical department or medical provider for low back pain. Both criteria had to be within the past 3 months. Workers were excluded if multiple injury sites were in the pain complaint. The injured employee was not recruited until the worker returned to full duty work. At the time of the injured worker's job assessment, an asymptomatic co-worker was recruited to perform the same job. The inclusion criteria for the asymptomatic worker included (1) the worker must be experienced in performing the job, (2) no history of low back pain or visits to a medical provider for low back pain, (3) no history of back surgery. Thus, a total of 400 workers participated in the study. Table 1 lists the means and standard deviation for anthropometric measures of both groups. These anthropometric measures have been defined in Marras and Kim (1993).

All of the low back injured workers completed a series of questionnaires to evaluate general health, low back pain symptoms, how the symptoms influenced activities of daily living, lost time and restricted time. Table 2 lists the mean and standard deviation from the SF-36 Health Survey raw untransformed scores (Ware *et al.* 1993), the McGill Pain Questionnaire (Melzack 1975), which includes a question on present pain intensity, and the Million Visual Analog Score (Million *et al.* 1982), which indicates the level at which the pain was interfering with activities of daily living. The McGill Pain Questionnaire scores are for pain levels on the days of testing. The low back injured workers reported an average of 12.7 (maximum 300) lost days due to this episode of back injury and 11.7 (maximum 180) restricted days. Sixty-eight percent of the population had less than 3 lost days due to the most recent low back injury and 53% had less than 3 restricted days. The pain scores reported in table 2 are from the day on which the testing was completed. The scores indicate that workers on average had symptoms between mild and discomforting back pain. In addition to the questionnaires, low back functional performance was evaluated using the clinical LMM protocol (Marras *et al.* 1999). The average low back functional performance probability of normal (Marras *et al.* 1999) from the injured workers was 0.21 (21% of the expected value given the age and gender) with a standard deviation of 0.25.

2.4. *Experimental design*

This was a case control study. The independent variable was low back health status. Health status was either low back injury in the past three months requiring a visit to a medical provider or asymptomatic. An ergonomic assessment using the LMM was completed on each worker performing at the same job. The jobs were divided into tasks depending on the complexity of the job. The maximum number of tasks was eight and the minimum was one. The same tasks were evaluated for both the injured and asymptomatic worker.

The dependent measures or job assessment measures were mean and maximum trunk kinematic measures of position, velocity, and acceleration in all three planes as the worker performed his or her job and workplace measures of lift rate, external load moment, moment arm, and start and finish heights as listed in tables 3 and 4. The external load moment was derived by weighing the load lifted and multiplying that by the measured horizontal distance from the worker's L5/S1 to the center of the hands. The job risk calculated from Marras *et al.* (1993) was a summary dependent measure. In addition, potential confounding individual anthropometric data were collected.

2.5. *Apparatus*

The LMM, an exoskeleton of the spine, was used to measure trunk motion. The LMM has been previously described and validated (Marras *et al.* 1992). Figure 1 shows the LMM on a worker. The LMM measures position, velocity and acceleration of the subject's thoraco-lumbar region in all three planes of the body.

Table 1. Anthropometric measures as a function of group.

Anthropometric measure	Low back injured	Asymptomatic	Paired *t*-test *p*-values
Age (years)	41.6 (10.2)	40.6 (11.1)	0.1551
Weight (kg)	84.6 (19.5)	83.4 (16.6)	0.4045
Standing height (cm)	174.2 (8.2)	175.7 (8.6)	0.0567
Shoulder height (cm)	144.9 (7.3)	145.9 (7.7)	0.1587
Elbow height (cm)	109.0 (5.6)	109.2 (6.0)	0.7296
Upper leg length (cm)	90.9 (6.1)	92.9 (6.0)	0.0005 *
Lower leg length (cm)	50.5 (4.2)	51.3 (4.3)	0.0213 *
Upper arm length (cm)	36.2 (2.6)	36.3 (2.7)	0.6579
Lower arm length (cm)	47.4 (3.1)	47.4 (3.4)	0.8558
Trunk length (cm)	51.7 (4.5)	52.7 (5.0)	0.0110 *
Trunk breadth at belly button (cm)	33.2 (3.8)	32.7 (3.6)	0.1051
Trunk depth at belly button (cm)	26.9 (5.1)	26.4 (4.9)	0.3161
Trunk circumference at belly button (cm)	98.7 (14.7)	96.7 (13.6)	0.1188
Percent male	72%	78%	0.0897

* Indicates significant difference at $\alpha = 0.05$.

In addition to the trunk motion measures, workplace measures of start and finish heights and load moment arm were measured with a tape measure.

2.6. *Procedure*

Upon arrival at the facility a company representative escorted the research team to the injured worker's job site. The research project was explained to the injured worker. The worker read and signed a University consent form. Anthropometric measures were collected on the worker and the LMM was placed on the worker. The worker returned to his or her full duty job. The trunk motions of at least three repetitions of each task were collected. Workplace measures were also collected as the worker performed each task. The procedure was completed for the injured worker first and repeated for the asymptomatic worker.

2.7. *Data analysis*

All the trunk motion characteristics and workplace measures from each repetition of each job task were entered into a database. The database represented 507 tasks with at least three repetitions of each task on each worker from all 200 jobs. The mean and maximum of the trunk motion and workplace measures from each worker were calculated by job. The low back disorder job risk for each worker was calculated using the five variable risk model developed by Marras *et al*. (1993).

2.8. *Statistical analyses*

The main aspect of the analyses was paired t-tests between the low back injured workers and the asymptomatic workers performing the same job. The workplace, trunk motion, anthropometry as well as job risk (Marras *et al*. 1993) were all compared as a function of low back status. As a supplemental analysis to the paired *t*-tests, equivalent models were fitted using SAS repeated measures procedures (Littell *et al*. 1996) in order to generate R^2 values for status and job (Vonesh *et al*. 1996). Finally, models were fitted for each anthropometric measure to determine the variance in risk explained by each measure.

Table 2. Low back injured workers' questionnaire results.

Questionnaire	Measurement	Mean	Standard deviation
SF-36 health survey	Physical function	22.9	5.96
	Role-physical	5.98	1.98
	Bodily-pain	7.18	2.14
	General health	18.6	4.91
	Vitality	14.1	4.32
	Social functioning	8.00	2.01
	Role emotional	5.10	1.27
	Mental health	24.8	3.70
	Reported health transition	2.96	1.02
McGill pain questionnaire	Present pain intensity	1.50	1.05
	Sensory word count	4.52	1.19
	Affective word count	1.02	1.58
	Evaluative word count	0.67	0.46
	Supplemental word count	1.36	1.31
	Total word count	7.57	5.78
Million visual analog score		49.8	27.2
Lost days for this episode		12.7	43.4
Restricted days for this episode		11.7	23.7
Lost and restricted days for this episode		22.3	53.9
Low back functional performance	Clinical LMM protocol probability of normal	0.21	0.25

3. Results

Tables 3 and 4 compare the group averages of the mean and maximum workplace and trunk motion measures, respectively, for the asymptomatic and low back pain subjects. Table 3 indicates that none of the workplace measures were significantly different between the two groups . In addition, none of the trunk motion measures were significantly different between the low back injured workers and asymptomatic workers (table 4). Anthropometric measures of trunk length, upper leg length and lower leg length were significantly different between the two groups of workers as shown in table 1, yet the difference in the anthropometric data did not result in differences in trunk motion measures or job risk.

The mean (standard deviation) job risk estimate for the low back pain workers was 0.502 (0.178) and for asymptomatic workers was 0.501 (0.193). Again, there was no significant difference between the two groups on risk (p-value = 0.9441). Figure 2 displays the differences in the risk model components between the injured workers and asymptomatic workers. Paired t-tests showed that none of the components were significantly different between the two groups. Analysis of variance indicated that the worker's health status explained less than 1% of the variance in low back risk of injury with a p-value of 0.8447, whereas the job explained 88% of the variance in risk of low back injury with a p-value of 0.0001. In terms of individual factors, age was the single most predictive anthropometric measure, which explained 3% of the variance and had a p-value of 0.0203. Trunk breadth, trunk depth and trunk circumference all had p-values of less than 0.05 but explained less than 2% of the variance. No other anthropometric measures significantly explained the variance of risk.

Table 3. Summary statistics of workplace measures for low back injured workers and asymptomatic controls.

Workplace measure	Low back injured	Asymptomatic	Paired *t*-test *p*-values
Mean lift rate (lifts/hour)	141.5 (129.1)	142.1 (129.0)	0.2477
Max lift rate (lifts/hour)	142.1 (128.8)	143.1 (129.2)	0.3092
Mean external load moment (Nm)	46.0 (36.9)	46.3 (36.1)	0.8079
Maximum external load moment (Nm)	89.9 (86.7)	88.8 (70.8)	0.8190
Mean load weight (N)	84.9 (63.1)	84.4 (62.6)	0.8208
Maximum load weight (N)	140.7 (96.9)	144.1 (110.8)	0.3761
Mean external load moment arm (m)	0.54 (0.11)	0.55 (0.1)	0.3124
Maximum external load moment arm (m)	0.73 (0.40)	0.71 (0.16)	0.4032
Mean start height (m)	0.99 (0.25)	1.01 (.26)	0.1375
Maximum start height (m)	1.25 (0.35)	1.26 (.34)	0.4216
Mean end height (m)	1.03 (0.24)	1.03 (0.23)	0.9230
Maximum end height (m)	1.30 (0.62)	1.26 (0.31)	0.0767

4. Discussion

The initial hypothesis that low back status or recent low back disorder would influence the risk of low back disorder due to the job (using the LMM risk model) was not found to be true. Low back status of the individual worker explained less than 1% of the variance in risk of low back injury whereas the job explained 88% of the risk variance. These findings indicate that risk of low back injury is almost entirely due to the design of the workplace as opposed to the individual differences amongst the workers. This implies that LMM risk assessment model is sensitive to workplace factors and should reduce the risk of low back disorder for all workers regardless of back health or individual factors.

On first consideration these findings may be surprising, since differences have been found between low back pain patients and asymptomatic controls in their trunk function (McIntyre *et al.* 1991, Masset and Malchaire 1994, Marras *et al.* 1995, 1999, McGill *et al.* 2003). In these previous studies the participants self selected the range of motion and speed at which their tasks were performed. Theoretically, trunk kinematics is driven by motor control muscle recruitment patterns that have been developed by each individual. It is hypothesized that low back pain patients would need to develop new muscle recruitment patterns resulting in differences in their trunk kinematics compared to asymptomatic controls. In the current study, the work pace and the job pressure to perform at a given speed were the same for each worker regardless of health status. Thus, it is hypothesized that the difference between findings is due to the control issue. In the work environment the trunk kinematics is controlled by job demands and not the worker, whereas, in the clinical assessment environment the person has full control. Although the trunk kinematic measures were not significantly different between the two groups, it is not known whether the motor control recruitment patterns were the same.

Even though the trunk kinematics, workplace measures and LMM risk assessment results were the same for low back injured workers and asymptomatic workers, the cost to the musculoskeletal system is probably greater for those with recent low back injuries. There are two hypotheses for the greater risk in those with recent low back injuries. First, Marras *et al.* (2004) found that those with low back pain had greater

Table 4. Summary statistics of trunk motion measures for low back injured workers and asymptomatic controls as they performed their job.

Trunk motion measures	Low back injured	Asymptomatic	Paired *t*-test *p*-values
Coronal plane			
Mean of minimum lateral position (deg)	− 7.04 (4.03)	− 7.48 (4.72)	0.2309
Mean of maximum lateral position (deg)	4.26 (4.18)	3.98 (3.79)	0.3744
Mean of lateral range of motion (deg)	11.30 (5.38)	11.45 (5.33)	0.6483
Mean of average lateral velocity (deg/sec)	6.08 (4.05)	5.34 (1.99)	0.9481
Mean of maximum lateral velocity (deg/sec)	22.13 (8.91)	22.10 (8.55)	0.9524
Mean of lateral acceleration (deg/sec^2)	156.2 (64.2)	154.2 (61.1)	0.6075
Max of minimum lateral position (deg)	− 1.00 (4.97)	− 1.49 (4.90)	0.2530
Max of maximum lateral position (deg)	10.5 (6.67)	10.4 (5.50)	0.7323
Max of lateral range of motion (deg)	19.5 (8.96)	19.2 (8.14)	0.6005
Max of average lateral velocity (deg/sec)	8.82 (3.67)	8.91 (3.54)	0.7504
Max of maximum lateral velocity (deg/sec)	36.6 (14.3)	36.8 (14.0)	0.8973
Max of lateral acceleration (deg/sec^2)	272.6 (111.1)	267.4 (104.1)	0.5123
Sagittal plane			
Mean of minimum sagittal position (deg)	− 6.32 (6.44)	− 5.71 (7.29)	0.3088
Mean of maximum sagittal position (deg)	6.83 (9.31)	7.34 (9.15)	0.4156
Mean of sagittal range of motion (deg)	13.16 (7.96)	13.05 (7.73)	0.7995
Mean of average sagittal velocity (deg/sec)	5.37 (2.27)	4.76 (2.07)	0.7166
Mean of maximum sagittal velocity (deg/sec)	22.1 (8.91)	19.92 (9.18)	0.9651
Mean of sagittal acceleration (deg/sec^2)	125.9 (52.3)	123.6 (48.8)	0.5111
Max of minimum sagittal position (deg)	1.11 (10.3)	1.59 (10.6)	0.5317
Max of maximum sagittal position (deg)	19.9 (14.2)	20.2 (13.7)	0.7575
Max of sagittal range of motion (deg)	26.3 (13.9)	26.0 (13.9)	0.6161
Max of average sagittal velocity (deg/sec)	8.55 (4.30)	8.88 (4.58)	0.2782
Max of maximum sagittal velocity (deg/sec)	38.7 (20.2)	39.5(23.0)	0.6504

(*continued overleaf*)

Table 4. (*continued*)

Trunk motion measures	Low back injured	Asymptomatic	Paired *t*-test *p*-values
Max of sagittal acceleration (deg/sec^2)	251.1 (131.7)	248.6 (129.5)	0.8145
Transverse plane			
Mean of minimum twist position (deg)	− 4.56 (5.11)	− 5.07 (5.99)	0.3071
Mean of maximum twist position (deg)	6.08 (4.05)	5.97 (6.48)	0.8119
Mean of twist range of motion (deg)	10.64 (5.58)	11.04 (5.65)	0.2630
Mean of average twist velocity (deg/sec)	4.71 (2.16)	4.60 (2.74)	0.7576
Mean of maximum twist velocity (deg/sec)	23.15 (11.35)	23.83 (11.33)	0.3576
Mean of twist acceleration (deg/sec^2)	157.8 (75.6)	159.4 (75.5)	0.7489
Max of minimum twist position (deg)	2.19 (5.24)	2.02 (5.17)	0.6912
Max of maximum twist position (deg)	12.1 (5.2)	11.9 (6.41)	0.7195
Max of twist range of motion (deg)	19.0 (8.6)	19.7 (8.51)	0.1793
Max of average twist velocity (deg/sec)	9.14 (5.11)	8.90 (5.21)	0.4605
Max of max twist velocity (deg/sec)	42.15 (18.6)	43.4 (19.2)	0.3693
Max of twist acceleration (deg/sec^2)	299.4 (132.4)	297.3 (136.0)	0.8258

muscle coactivity, which resulted in greater spine loading during the same lifting tasks. Thus, the worker with a recent low back pain episode may be co-contracting their muscles, resulting in greater spine loading and thus greater risk of further injury. Second the recently injured worker may have lower spinal loading tolerance. The spinal structures may be compromized by the recent injury and even though the worker has returned to full duty work the spine structure may not be fully recovered from a material integrity viewpoint. Thus, the spine structures including discs, ligaments, muscles and bones may be further damaged at a lower loading level than in the original injury. Along with lower spine tolerances, pain pathways may be more easily stimulated due to the recent injury, resulting in pain symptoms at lower threshold levels. Thus, this risk model may underestimate the risk for low back disorder workers.

Since kinematic behaviour is dictated by the job and not the person the LMM risk assessment results showed no difference between workers with recent low back injuries and asymptomatic worker performing the same job. This finding suggests that low back health status does not influence the risk of low back injury when measured with the LMM. However, the literature indicates that those with previous history of low back injury are at increased risk of injury (Bigos *et al* 1991, Punnett *et al*. 1991, Papageorgiou *et al*. 1996, Burton 1997, Ferguson and Marras 1997, Van Poppel *et al*. 1998, Kerr *et al*. 2001). Thus, it is hypothesized that the risk measured with the LMM indicates the risk of low back injury for an asymptomatic individual

Figure 1. The lumbar motion monitor (LMM) worn by a worker performing a manual material handling job.

and that risk is probably greater for those with previous history of low back disorders. This hypothesis is supported by findings of Marras *et al.* (2004) discussed above which found increased muscle co-activity resulting in greater spine loading and therefore increased risk of low back injury.

There were several limitations to this study. First, most of the injured workers in the study had self-reported muscular back pain severe enough to warrant a visit to the plant medical department. Workers with disorders such as herniated discs or spinal stenosis may have different outcomes. The second limitation is that the study

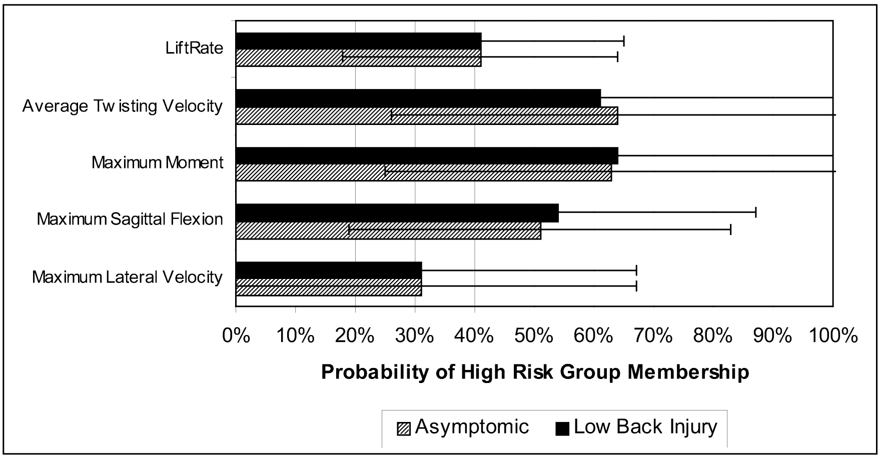

Figure 2. Mean and standard deviation of components for probability of high risk group membership for both asymptomatic workers and low back injury workers.

relied on workers' self-reports of being pain free for inclusion in the control group. A third limitation is that this study reflects manufacturing type work environments only. However the jobs represented many types of manufacturing work.

5. Conclusions

There was no significant difference in the probability of high risk group membership for low back disorder between low back injured workers and asymptomatic workers performing the same job. The LMM risk estimates appear to be dictated by the job and not influenced by the low back health status of the worker.

Acknowledgements

This project was supported by a grant from the Ohio Bureau of Workers' Compensation (BWC). The authors would like to thank all the participating companies for supporting this research. The authors would also like to thank Chris Hamrick M.S., Anthony Maronitis, M.S., Pete Schabo, Riley Splittstoesser, M.S., and Dr. Mike Jorgensen, Ph.D. for assisting in the data collection process.

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