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Partitioning the contributing role of biomechanical, psychosocial, and individual risk factors in the development of spine loads

Kermit G. Davis, PhD[a,b,*], William S. Marras, PhD[b]

[a]Low Back Biomechanics and Workplace Stress Laboratory, Department of Environmental Health, The University of Cincinnati, 3223 Eden Avenue, Cincinnati, OH 45267-0056, USA

[b]Biodynamics Laboratory, The Ohio State University, 1971 Neil Avenue, 210 Baker Systems, Columbus, OH 43210, USA

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Abstract

BACKGROUND CONTEXT: The role of biomechanical workplace factors in spine loading has been well documented. However, our understanding of the role of psychosocial and individual factors in producing spine loads is poorly understood. Even less is understood about the relative contribution of these factors with respect to kinematic, kinetic and muscle activity responses, as well as spine loading.

PURPOSE: To explore the relative contribution of biomechanical and psychosocial workplace factors and individual characteristics on the biomechanical responses and spine loading.

STUDY DESIGN/SETTING: The contribution of various levels of workplace factors to spine loading was monitored under laboratory conditions.

PATIENT SAMPLE: Sixty (30 male and 30 female) college-age individuals who were asymptomatic to low back pain.

OUTCOME MEASURES: Trunk kinematics and kinetics, muscle activity and the three-dimensional spinal loads.

METHODS: The subjects performed lifting tasks while being exposed to varying levels of biomechanical (lift rate, load weight and task asymmetry) and psychosocial (social support and mental concentration) workplace factors as well as an unexplored (load placement) workplace factor.

RESULTS: The workplace job demands that had the largest contribution were load placement (4% to 30%) and load weight (15% to 55%). Mental concentration and social environment had a relatively small contribution to the spinal loads (up to 0.2%). Anthropometry played a large role in the shears (about 12% to 58%) but a relatively minor role in the compressive forces (about 3%).

CONCLUSIONS: Under the given experimental conditions, load weight is the most important factor when controlling compression forces associated with lifting, but other factors, such as individual characteristics, significantly contribute to the shear loads. Thus, one must account for the weight lifted and the anthropometric dimensions when designing the workplace. For the first time, the relative contribution of workplace job demands and individual factors in the development of spine loading have been identified.

Keywords: Trunk kinematics; Trunk kinetics; Electromyography; Spine loading; Ergonomics

Introduction

It is common knowledge that low back pain (LBP) has a tremendous impact on society. At some time during their lives, the majority of the working population (over 80%) experience LBP [1,2], with a yearly prevalence of 17.6% [3]. Epidemiological studies have reported three general classifications of risk factors to be associated with LBP: biomechanical, psychosocial and personal. The biomechanical factors relating exposures to LBP are weight lifted, task asymmetry, lift rate, box position and reach distances, and the psychosocial risk factors consist of mental concentration or demands, job responsibility, lack of variety, job satisfaction and mental stress [1,4–12]. Personal factors have also been identified as potential risk factors for LBP, such as

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* Corresponding author. Department of Environmental Health, University of Cincinnati, Cincinnati, OH 45267-0056, USA. Tel.: (513) 558-2809; fax: (513) 558-4397.

E-mail address: kermit.davis@uc.edu (K. Davis)

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physical strength, genetics, anthropometry, gender and personality (e.g., height and weight) [1,5,7,8,13–18].

Laboratory studies have started to investigate the underlying factors that cause LBP through the use of sophisticated equipment (e.g., lumbar motion monitor [LMM], electromygraphy) and spine loading models. This approach is based on a load-tolerance perspective: damage occurs when a load on a spine structure exceeds its tolerance [19–21]. The literature is dominated by studies investigating the impact of biomechanical factors on the spine load response. Weighted lifted, position of the box (e.g., reach distances and height), task asymmetry and lift rate have all been found to significantly increase the three-dimensional spinal loads [22–30]. Two studies have investigated the impact of psychosocial factors on spine loading. Marras et al. [31] reported increases in mental stress–produced kinematic and coactivity responses that increased the three-dimensional loads. Davis et al. [32] reported increased spinal loads with mental demands and lifting demands occurring simultaneously. Furthermore, individual factors, such as gender, anthropometry and personality, may contribute to loading as well as influence the loading response to the work factors (modifier), both psychosocial and biomechanical [24,33–36].

This brief review has shown that the effect of physical workplace design on spine loading has been well documented. However, how biomechanical workplace factors compare with the contribution of psychosocial and individual factors in producing spine loads is poorly understood. The current study investigated the relative contribution of biomechanical and psychosocial workplace stressors, as well as individual characteristics on the trunk kinematics and kinetics, muscle coactivity and resulting spine loads.

Methods

Experimental task

A free-dynamic lifting task was performed to evaluate the contribution of biomechanical, psychosocial and individual factors on spine loads. Subjects lifted boxes from a conveyor positioned directly in front of them to a destination shelf positioned either 90 degrees clockwise or counterclockwise (Fig. 1).

Subjects

Thirty male and 30 female students (asymptomatic for the previous year) were recruited for the study. The mean (SD) height and weight for the women were 166.6 (4.5) cm and 62.0 (7.8) kg and for the men were 178.6 (8.0) cm and 79.0 (11.4) kg, respectively. Personality of the individuals was determined using the Myers-Briggs Type Indicator [37]. Extroverts outnumbered introverts by a 2 to 1 margin, and the other pairs of personality traits were more evenly split.

Experimental design

The independent variables were load weight (6.8 and 11.4 kg), task asymmetry (90 degrees clockwise, 90 degrees counterclockwise), mental concentration (none and number identification), load placement (general and specific), lift rate (2 lifts/minute and 8 lifts/minute) and social environment (good and poor). For the number identification condition, subjects had to decide where (asymmetry) and how (load placement) to place the box. The "specific" placement conditions required the box to be placed within the target area (1.3 cm tolerance around the box), whereas "general" placement conditions had the box placed in the general vicinity of the target area. During the "good" social environment, the experimenter was jovial and provided encouragement to the subject. On the other hand, another experimenter was in charge of the "poor" social environment condition and appeared to be upset about interruptions with the experiment and was short with the subject (e.g., no small talk, straight to the point).

The dependent variables were the muscle coactivity of the 10 trunk lifting muscles, three-dimensional kinematics (position and velocity), trunk moments and spine loads (shears and compression) that were determined using the electromyograph (EMG)-assisted model developed over the last 18 years in the Biodynamics Laboratory [27,28,35,36,38–48]. The model provides estimates of the sagittal, lateral and axial trunk moments as well as compression, lateral shear and anterior-posterior shear forces on the spine at L5–S1.

Apparatus

The LMM measured the trunk motion characteristics during the lifting tasks. The LMM is essentially an exoskeleton of the spine in the form of a triaxial electrogonio-

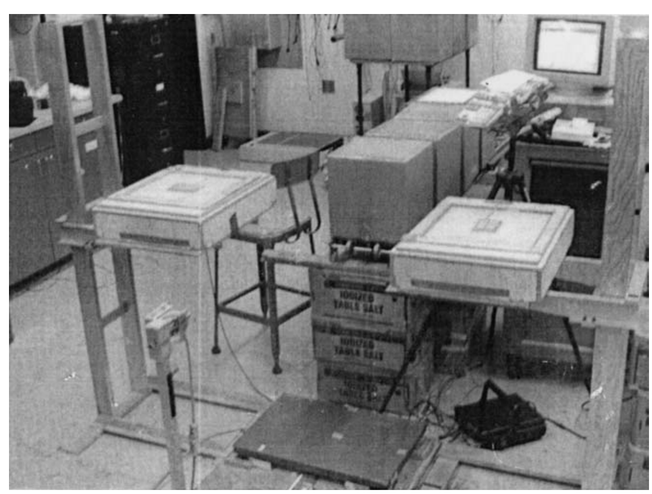

Fig. 1. Experimental layout with the forceplate and the destination shelves at 90 degrees clockwise and 90 degrees counterclockwise. The subject types the number located on the top of the box into the keypad located in front of the computer (right of the subject) and then lifts the box from the conveyor located directly in front.

meter that measures the instantaneous three-dimensional position, velocity and acceleration. For more detail about the design, accuracy and application of the LMM, refer to Marras et al. [49].

EMG activity was collected from the five pairs of trunk muscles through the use of bipolar silver-silver chloride surface electrodes spaced approximately 3 cm apart. EMG activity was collected from the five pairs of trunk muscles (right and left pairs of latissimus dorsi, erector spinae, rectus abdominus, external obliques and internal obliques) through the use of bipolar surface electrodes [48]. The EMG signals were preamplified, high-pass filtered at 30 Hz, low-pass filtered at 1,000 Hz, rectified and integrated by means of a 20-ms sliding window hardware filter.

A forceplate and set of electrogoniometers were used to accurately estimate the moments supported by the trunk during the lifts. The electrogoniometers assess the position of L5–S1 relative to the center of the forceplate as well as measure the pelvic/hip orientation. The force and moments measured at the center of the forceplate are then translated and rotated to L5–S1 by the method developed by Fathallah et al. [50].

Boxes were made of corrugated cardboard with the dimensions of 31 cm × 31 cm × 31 cm. The eight-digit number was labeled in the upper left-hand corner with four color-coded positions. The color codes allowed for easy randomization of the boxes on the conveyor by the experimenters (e.g., allowed for easy setup). The subjects were told only to use the number facing them on the box and ignore all other numbers.

Procedure

Upon arrival at the Biodynamics Laboratory, the subjects were briefed about the concentration and lifting tasks during the experiment. The subjects then read and signed a consent form and completed the Myers-Briggs Type Indicator [37]. The five pairs of surface electrodes were applied to the subject using standard EMG techniques [51]. The skin impedance was kept under 100 MΩ to ensure high-quality EMG signal. The subjects were then placed in a rigid structure where maximum isometric exertions were performed. These standard six maximum exertions were used for normalization of the EMG data [52]. Upon completion of the maximum exertions, the subject was fitted with an LMM and positioned on the forceplate, where the experimenter again went over the mental concentration protocol.

During a practice session, the subject lifted boxes containing no weight to the appropriate places by reading the numbers on top of the boxes. Subjects were instructed to type in the number, decide where to place the box and then lift the box to the appropriate position. The subject was to maintain the lift rate but could correct any typing errors when time allowed. In other words, they had to lift the next box when the next beep went off, but if they had time they could correct any mistakes (e.g., slow lift rate allowed time to correct the number just entered into the computer). The practice session started with the slow lift rate (2 lifts/minute). When the subject became familiar with the process, the lift rate was then switched to 8 lifts/minute and the practice session continued. When the subject was comfortable with the concentration task (e.g., verbal confirmation and several lifts without any placement errors), initial readings of the forceplate, LMM, electrogoniometers, blood pressure and heart rate were recorded. Subjects also completed the initial State-Trait Anxiety Inventory, which assessed the baseline anxiety of the individual [53].

At this point, the experiment was interrupted with the original experimenter being asked to leave the room. The new experimenter (who was in charge of the "good" social environment conditions) replaced him, and the first set of lifts was completed. For each combination of mental concentration (none or typing task), social environment ("poor" and "good"), lift rate (two and eight lifts/minute) and load weight (6.8 and 11.4 kg), a set of eight lifts that corresponded to two lifts for each combination of task asymmetry (clockwise and counterclockwise) and placement control (controlled and general) were performed. Sets of eight lifts were performed in random order with the eight lifts being performed within each set. No matter which experimenter was present, heart rate and blood pressure, as well as a State-Trait Anxiety Inventory questionnaire, were collected after each set of eight lifts (e.g., two lifts of each combination of task asymmetry and placement control for each set).

Upon completion of all the sets of lifts, the subject was debriefed about the true nature of the study: evaluation of the contribution of biomechanical factors, mental concentration and social environment. Subjects were also informed about the switch used to trigger the buzzer when the box was successfully placed within the target correctly. Finally, complete anthropometric measurements were taken.

Data analyses

Customized software converted the voltages recorded from the LMM into trunk angles, velocities and accelerations. The EMG activities for each of the muscles were normalized to the values obtained during the six maximum exertions. Normalized EMG, kinematic and kinetic data were inputted into the EMG-assisted model to obtain the predicted trunk moments and spinal loads. Maximum values were determined for all the responses and spinal load variables.

Statistical analyses

Multiple linear regression techniques were used to determine the contribution of the biomechanical, psychosocial and individual factors on the trunk kinematics and kinetics, muscle coactivity and resulting spine loads. The amount of "relative variance explained" refers to the proportion of the total explained variability in the spine load variable that can be attributed to the corresponding predictive variable and was calculated by comparing the partial R^2 for the regression equations.

Results

During lifting, workplace factors and individual characteristics produce kinetic and kinematic responses that are needed to lift the object. With these kinematic and kinetic changes, a muscle activation pattern is elicited that drives the motion and force response. Furthermore, the muscle activation produces three-dimensional loads on the spine. Understanding this progression and how individual factors contribute to the responses and spinal loads may lead to better interventions for the control of LBP.

Spinal loads

The relative contribution of the factors in the development of spinal loads was dependent on the direction of the load (e.g., compression vs. shear). The workplace job demands that had the largest contribution were load placement (4% to 30%) and load weight (15% to 55%; see Fig. 2). Mental concentration and social environment had a relatively small impact on the spinal loads (up to 0.2%). Personality also contributed significantly to the variability in the spinal loads (about 6% to 19% of the explained variability). Anthropometry played a large role in the shears (about 12% to 58%) but a relatively minor role in the compressive forces (about 3%). Gender had a limited influence on the spinal loads (0.7% to 13.4%).

Muscle activity

Fig. 3 shows the contribution of the workplace job demands and individual factors on the agonistic (extensor) and antagonistic (flexor) muscle activity. In both cases, load weight (14% to 17%), anthropometry (17% to 20%) and gender (40% to 43%) had the largest impact on muscle activity. Load placement also explained 3% to 4% of the relative variability, whereas task asymmetry explained about 4% of the extensor and 14% of the flexor activity variability.

Trunk kinematics

The portion of the explained variability for the trunk postures and velocities are shown in Fig. 4. Individual (e.g., anthropometry, gender and personality) variables play a large role in trunk kinematic characteristics, accounting for more than 79% of the explained variability. Load weight, task asymmetry and load placement (about 6% to 7%) were the job demands that had the greatest influence on the

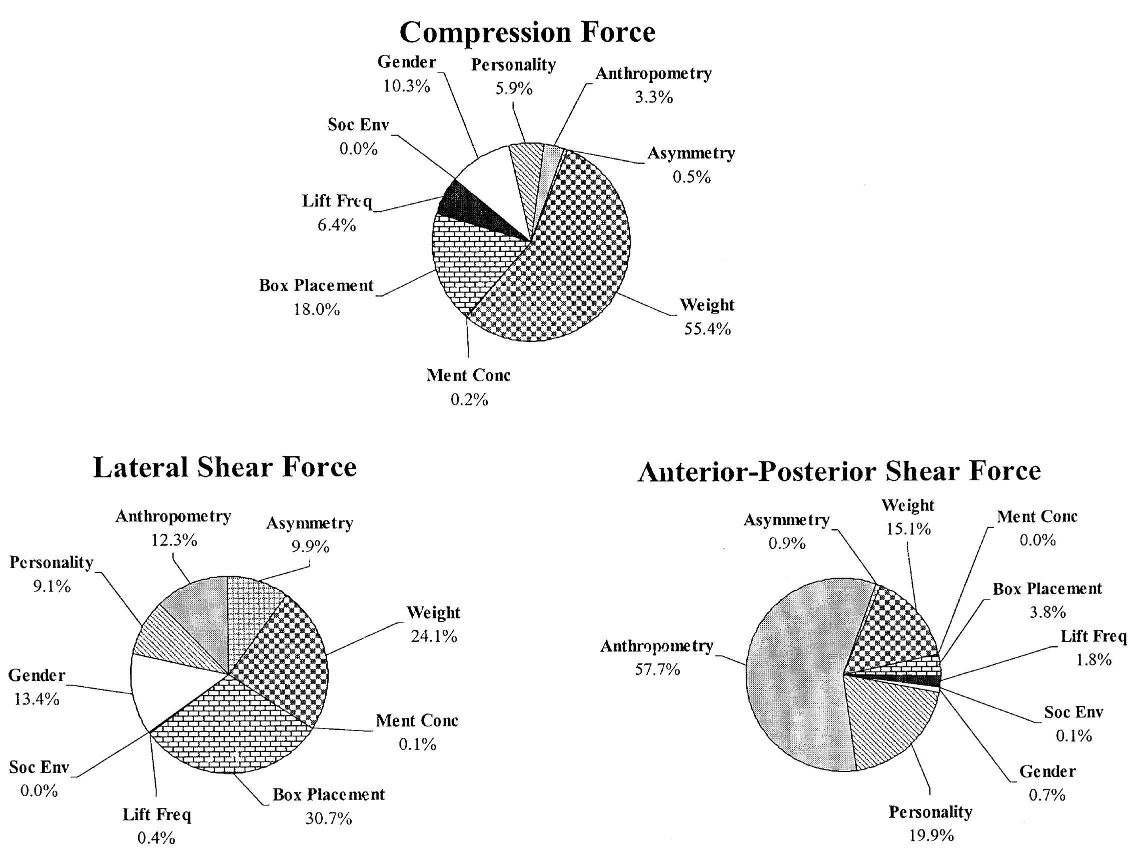

Fig. 2. Amount of relative variance in compression, lateral shear and anterior-posterior shear forces explained by the workplace job demands and modifiers (as predicted by the partial R^2 values). Freq = frequency; soc env = social environment; ment conc = mental concentration.

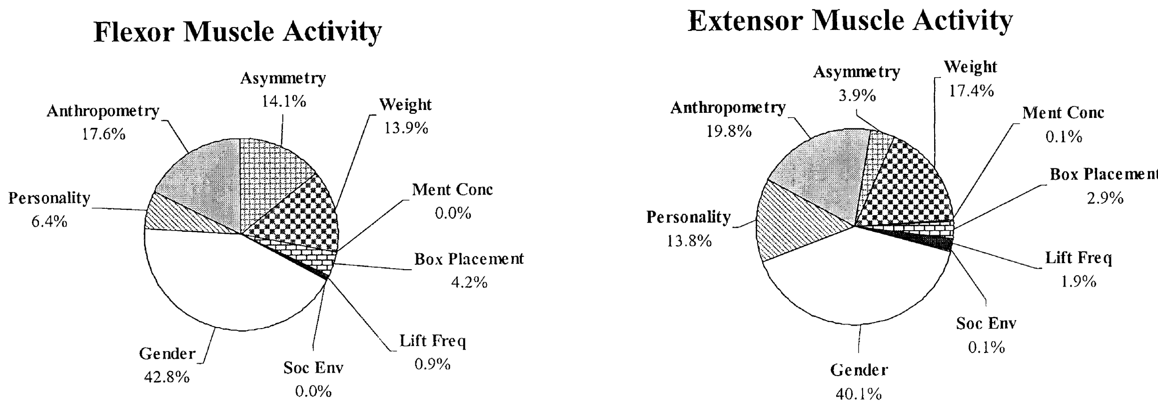

Fig. 3. Amount of relative variance in extensor (latissimus dorsi, erector spinae and internal obliques averaged) and flexor (rectus abdominus and external obliques averaged) muscle activity explained by the workplace job demands and modifiers (as predicted by the partial R^2 values). Freq = frequency; soc env = social environment; ment conc = mental concentration.

trunk postures, whereas lift rate had the highest impact on trunk velocity (4.5%). Basically, the body dimensions of the individual had, by far, the greatest influence on the trunk postures and motions during the lifting tasks.

Trunk kinetics

The amount of variability explained for trunk kinetics was relatively similar for gender, anthropometry, personality and load weight (15% to 30%; see Fig. 5). Load placement was also found to mildly influence the trunk moments during the lifting (4.5%). For the trunk moments, the explained variability was predominantly accounted for by both individual factors (e.g., anthropometry, gender, personality) and load weight.

Discussion

Before the implications of the results are discussed, limitation issues should be addressed. First, it may be improper to generalize these results to all circumstances. These results apply to this particular experiment and its specific conditions. A study with different experimental conditions may have different relative contributions of the specific factors with respect to the biomechanical responses (e.g., trunk kinetics and kinematics, muscle activity) and spine loads. One example of this would be that the independent variables had only a few levels (e.g., two); thus, limited variability may misrepresent the relative contribution of these variables in the workplace. The models used dichotomous variables to predict continuous responses. Such factors as task asymmetry may also have a greater contribution with additional levels (e.g., 45 degrees) rather than two similar conditions (e.g., 90 degrees clockwise vs. 90 degrees counterclockwise). The relative importance of the variables may also be dependent on the magnitude of the levels selected. For example, the lack of importance of the psychosocial factors may have been the result of the type of demands on the individual. In other words, the contribution of mental concentration might have been larger if the task had been more complex and demanding. The relative contributions may also be dependent on the current subject population. Although the number of subjects was large (n = 60), the subjects were limited to students who had limited experience with manual material handling. More experienced subjects might have had a different breakdown in the relative contributions. Furthermore, the experimental setup may have also influenced

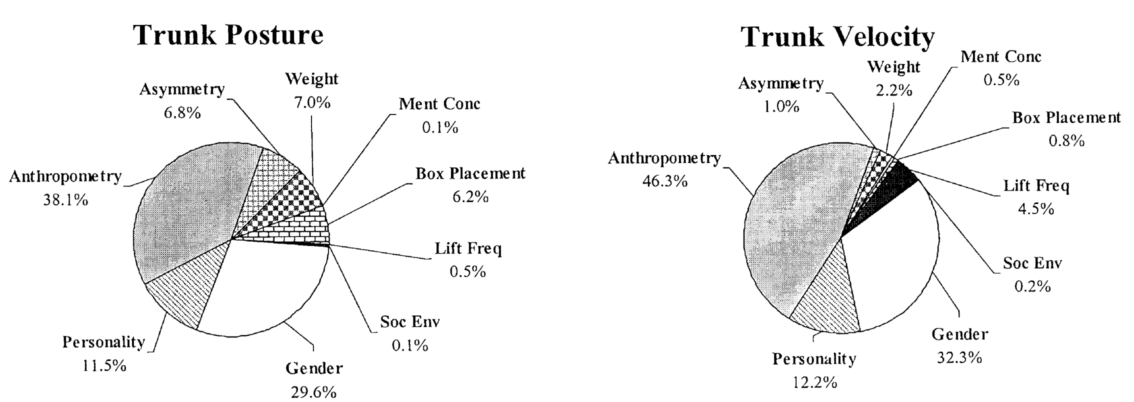

Fig. 4. Amount of relative variance in trunk posture and velocity (sagittal, lateral and twist averaged) explained by the workplace job demands and modifiers (as predicted by the partial R^2 values). Freq = frequency; soc env = social environment; ment conc = mental concentration.

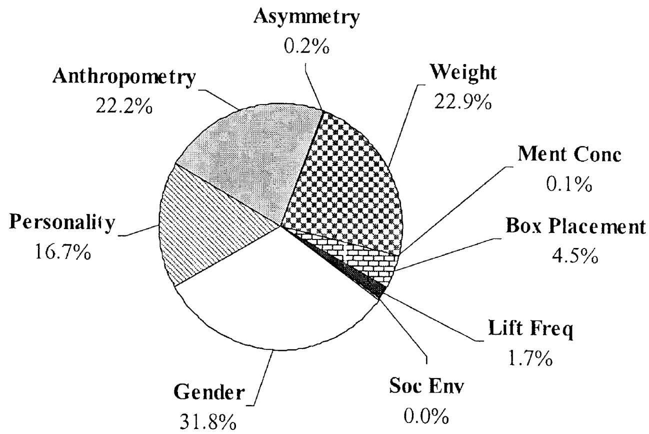

Fig. 5. Amount of relative variance in trunk moments (sagittal, lateral and twist averaged) explained by the workplace job demands and modifiers (as predicted by the partial R^2 values). Freq = frequency; soc env = social environment; ment conc = mental concentration.

the relative contributions. The work environment was fixed in two ways: 1) feet were stationary on the forceplate, and 2) conveyor and shelves were at the same position for all subjects. Nonadjustable heights and distances may have magnified the contribution of the biomechanical parameters (e.g., load weight and load placement) and anthropometry by exacerbating the trunk kinetic and kinematic responses.

Regarding the above issues, the study has demonstrated how different factors might impact different types of loading and the biomechanical responses that lead to them. The current study provides an initial picture of the relative contribution of biomechanical and psychosocial workplace job demands as well as individual factors in the development of spine loading. As expected, load weight contributed significantly to compression force (more than 55% of the explained variability); however, load weight had a lesser role in the resulting shear forces (15% to 25%). Thus, weight-based controls may be more applicable in reducing compressive forces on the spine but may neglect shear loading.

On the other hand, individual factors, such as personality, anthropometry and gender, had a larger role in the shear loads but a relatively limited influence on compression. This large contribution of anthropometry (in excess of 20% of the explained variability) in the shear loading regression models may reveal the importance of workplace design, in that the workplace was "stationary" in nature (e.g., no adjustability of shelves or conveyor to the worker, inability to move feet). In other words, ergonomic controls in the form of adjustable equipment may have lessened the impact of anthropometry. For example, by fitting the worker to the workplace, the more extreme postures may have been reduced, thus reducing the effect of taller standing heights or lessening the impact of heavier upper torsos. Thus, ergonomic controls that account for body dimensions and reduce the weight lifted have the greatest potential of impacting the loads on the spine.

Psychosocial factors (mental concentration and social environment) had minimal contribution to the loads relative to the other factors. One explanation for this lack of impact for psychosocial factors (mental concentration and social environment) may be the relatively large contribution of personality. The variation explained by personality may account for similar variance resulting from psychosocial factors. In other words, psychosocial reactions may be directly related to the personality of the individual. Another explanation is that psychosocial factors may have a relatively small impact on the spine loads and may act more as modifiers. In other words, psychosocial factors may contribute more interactively, actually magnifying the effect of the biomechanical factors.

Perhaps the most unexpected finding in this study involved the large influence of load placement in the resulting spine loads. Load placement is a unique stressor, in that it has both biomechanical and psychosocial components. During the controlled placement condition, the subjects were required to hold the box at extended distance (biomechanical) and concentrate on its position (psychosocial) as the box was lowered into position. Basically, mental processing and biomechanical lifting of the box occurred simultaneously, potentially taxing multiple components of the musculoskeletal system. The sizeable influence of load placement indicates the importance of considering nontraditional and more complex workplace factors when trying to reduce spine loading and to control the development of low back disorders. This may be particularly important considering the complexity of the workplace resulting from technologic advances and lean manufacturing.

The change in the relative contribution across the models may be an indication of the complex relationship among kinematics, kinetics and muscle coactivity. In general, the relative contributions of the factors for trunk kinematics and kinetics were very similar to those for muscle coactivity. The common breakdown within these models supports the logic that the trunk motion and moments lifted produce the muscle coactivity pattern, and it is the combination of these responses that produce the loads on the spine. In other words, the contribution of muscle activation to the spine loads depends on the position and velocity of the trunk (e.g., trunk kinematics). Thus, a trade-off between muscle activity and trunk kinematics may have resulted that reduced the contribution of gender and other factors on spine loads.

Conclusion

Biomechanical workplace factors, individual characteristics and, to a lesser extent, psychosocial factors contribute to three-dimensional spine loading. Given these experimental conditions, load weight was the major contributor to compression, whereas individual characteristics accounted for the majority of anteroposterior shear variability. Biomechanical workplace factors, individual characteristics and load placement (combination of psychosocial and biomechanical aspects) contributed equally to the lateral shear forces. The results stress the importance of ergonomic controls, particularly, fitting the individual to the workplace. More importantly, this study points to the importance of considering a multitude of factors when attempting to control the load placed on the spine.

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Thirty-five Years Ago in Spine . . .

The effective use of behavior modification for control of chronic pain was described by Wilbur Fordyce and his coworkers in 1968 [1]. Their work, which described how treatment concepts could be integrated with new understandings of the psychophysiology of chronic pain, was a strong catalyst to the use of integrative therapies to displace traditional medical treatments for chronic pain control. Ten years after their work was published, 325 pain clinics were operating in the United States.

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