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RELATIVE CONTRIBUTION OF WORKPLACE FACTORS AND INDIVIDUAL CHARACTERISTICS IN THE DEVELOPMENT OF SPINE LOADS

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Thirty males and thirty females performed lifting tasks while being exposed to varying levels of physical (box weight, task asymmetry), psychosocial (social support and mental concentration), and combination (lift rate, box placement) workplace factors. The study investigated the impact of these variables as well as individual factors (gender, personality) on trunk kinematics and kinetics, muscle activity, and the three-dimensional spinal loads. The study results indicate box weight, placement control, individual's anthropometry, and to a lesser extent gender and personality directly impact the loads on the spine as well as the trunk kinematics, kinetics, and muscle activity. Both the physical and mental aspects of the workplace must then be considered when developing ergonomic interventions.

INTRODUCTION

It is common knowledge that low back pain (LBP) has a tremendous impact on society. One frequently utilized approach when investigating the underlying factors that cause LBP is spinal loading models. This approach is based upon a load-tolerance perspective—damage occurs when a load on a spine structure exceeds its tolerance (McGill, 1997).

The literature is dominated by studies investigating the impact of biomechanical factors on the spine load response. Numerous studies have found the amount of weight lifted has a substantial impact on the spine loads (de Looze et al., 1996, Dolan et al., 1999, Drury et al., 1989, Fathallah et al., 1998, Granata et al., 1999, Han et al., 1995, Marras et al., 1999, Marras and Sommerich, 1991). Another biomechanical factor often found to significantly impact the three-dimensional loads is task asymmetry (Fathallah et al., 1998, Granata and Marras, 1995, Granata et al., 1999, Marras and Davis, 1998, Marras and Sommerich, 1991). Although psychosocial work characteristics have gained popularity as potential risk factors for LBP in epidemiological studies (Bongers et al., 1993, Burdorf and Sorock, 1997, Davis and Heaney, *2000, Ferguson and Marras, 1997*), there are no studies that have investigated the impact of potential psychosocial risk factors such as mental demands, social environment, job content, and lack of variety on spine loads.

Other factors such as lift rate and placement control have both biomechanical and psychosocial aspects that may contribute to spine loading. For example, controlled box placement has a biomechanical component due to the holding of the box and a psychosocial component due to the mental concentration and potential of failure. Similarly, lift rate has the biomechanical component of increased physical demands and being hectic (feeling rushed), which relates to the psychosocial domain. To date, these combination factors have not been investigated, especially with respect to spine loading.

Further, 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 (Drury et al., 1989, Leskinen et al., 1992, Marras et al., 2000, 2002). This brief review has shown that the role of physical workplace design upon spine loading has been well documented, however our understanding of the role of psychosocial and individual factors as well as combination factors such as lift rate and placement control in producing spine loads is poorly understood. The current study investigated the relative impact of all four types of factors (biomechanical, psychosocial, combination, and individual) 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 impact of physical, psychosocial, and individual factors on the spine loads. Subjects lifted boxes from a conveyor positioned directly in front of them to a destination shelf positioned either 90° clockwise or counter-clockwise.

Subjects

Thirty male and thirty female students (asymptomatic for the previous year) were recruited for the study. The mean (std dev) height and weight for the females were 166.6 (4.5) cm and 62.0 (7.8) kg and for the males 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 (MBTI) (Myers and Myers, 1998). Extraverts outnumbered Introverts by a 2 to 1 margin while the other pairs of personality traits were almost evenly split.

Experimental Design

The *independent variables* were box weight (6.8 and 11.4 kg), task asymmetry (90° clockwise, 90° counter-clockwise), mental concentration (none and number identification), box placement (general and specific), lift rate (2 lifts/min and 8 lifts/min), and social environment (good and poor). For the number identification condition, subjects had to decide where (asymmetry) and how (placement position) to place the box. The "specific" conditions required the box be placed within the target area while "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 who appeared upset about experimental interruptions was in charge of the 'poor' social environment condition.

The *dependent variables* were the muscle coactivity of the ten trunk lifting muscles, three-dimensional kinematics, trunk moments, and spine loads (shears and compression) that were determined using the EMG-assisted model developed over the last 18 years in the Biodynamics Laboratory (Davis et al., 1998, Fathallah et al., 1998, Granata and Marras, 1995, Granata et al., 1999, Marras and Granata, 1995, Marras et al., 2002, Marras and Sommerich, 1991, Mirka and Marras, 1993).

Apparatus

The lumbar motion monitor (LMM) measured the trunk motion characteristics during the lifting tasks (Marras et al., 1992). Electromyographic (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 (Marras and Mirka, 1993). The EMG signals were pre-amplified, high-passed filtered at 30 Hz, low-passed filtered at 1000 Hz, rectified, and integrated via a 20 ms sliding window hardware filter. A forceplate and set of electro-goniometers was used to accurately estimate the trunk moments (Fathallah et al., 1997).

Procedure

Subjects were briefed about the study, read and signed the consent form, completed the MBTI (Myers and Myers, 1998), and anthropometry was recorded. Electrodes were applied to the subject using standard EMG techniques (Marras, 1990) followed by completion of the maximum exertions used for normalization (Marras and Mirka, 1993). After the subject was fitted with a LMM and positioned on the forceplate, a practice session was completed with boxes containing no weight. At this point, the 'good' social environment experimenter interrupted and completed the first set of lifts. For each combination of the independent variables, sets of eight lifts were performed in random order. The two experimenters would enter and leave the room at the appropriate times corresponding to the type of social environment ('good' and 'poor').

Statistical Analyses

Multiple linear regression techniques were also used to determine the impact 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.

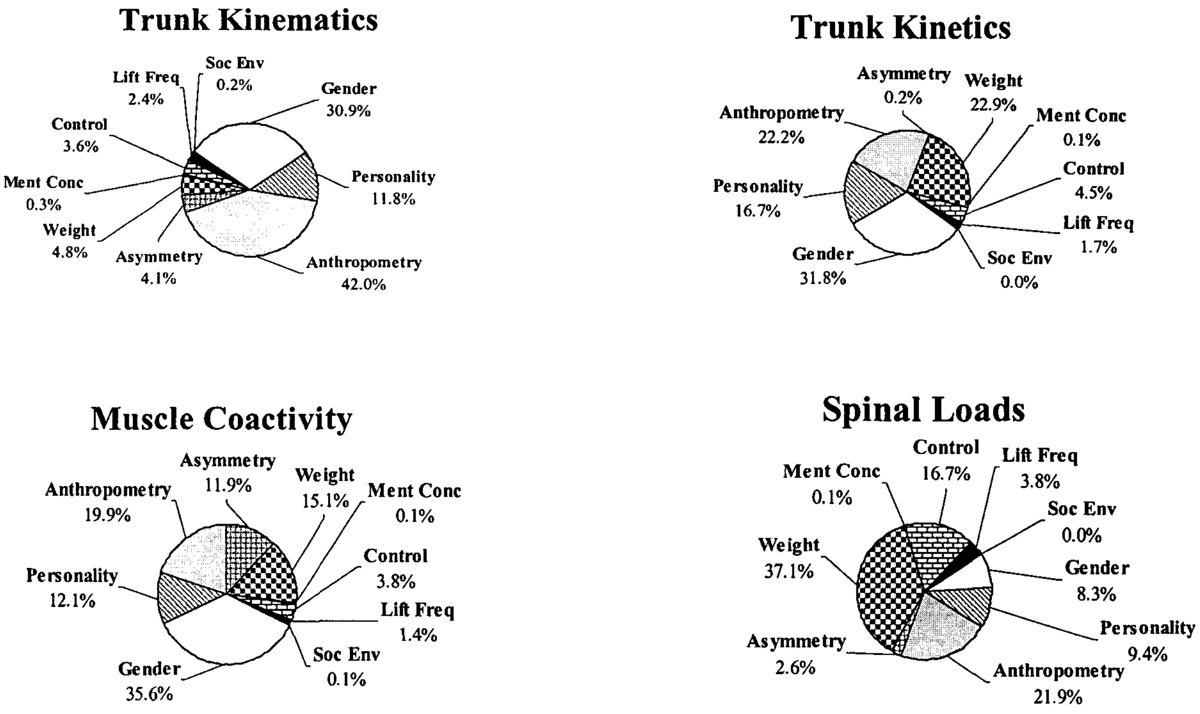

Figure 1: Relative contributions of biomechanical, psychosocial, and individual factors to the trunk kinematics, trunk moments, muscle coactivity, and spine loading.

RESULTS

Figure 1 shows the relative contributions for the biomechanical, psychosocial, combination, and individual factors for trunk kinematics, trunk kinetics, muscle coactivity, and spine loads. Individual factors had a large impact in the kinematic and kinetic response (accounted for over 70% of the explained variability). As expected, box weight had a large impact on the trunk moments (22.9%). Placement control accounted for about 5% of the explained variability of trunk kinematics and kinetics. Lift rate had a small impact on the kinematic and kinetic responses. Psychosocial variables (social support and mental concentration) had a very limited impact (<1%).

A similar pattern was found for muscle coactivity with individual factors accounting for the largest explained variability. Box weight and task asymmetry accounted for 15% and 12% of the explained variability in muscle coactivity. Combination factors account for 1 to 4% of the variability in muscle coactivity.

An interesting pattern existed with the spine load models. Individual factors have less impact on the spine loads while biomechanical and combination factors account for a significantly greater amount of explained variability. Box weight (37.1%), placement control (16.7%), and anthropometry (21.9%) are the factors that impact spine loading the most with psychosocial factors having minimal impact.

DISCUSSION

The current study provides an initial picture of the evidence linking workplace job demands and individual factors to loading on the spine. Although individual factors had a dominating role in the kinematics, kinetics, and muscle coactivity models, biomechanical workplace factors were the main contributors to the spine load models. The order of influence in determining the spine loading in this study was: 1) box weight, 2) anthropometry, 3) placement control, 4) personality, 5) gender, 6) lift frequency, 7) asymmetry, 8) mental concentration, and 9) social environment.

As expected, box weight was the major contributor to the spinal loads but the impact of anthropometry was not expected. The large impact of anthropometry (in excess of 20% of the explained variability) in the regression models may reveal the importance of ergonomics, 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, and thus reducing the effect of taller standing heights. Thus, ergonomic controls that account for body dimensions and reduce the weight lifted have the greatest potential in impacting the loads on the spine.

On the other hand, psychosocial factors (mental concentration and social environment) have a very minimal impact on the loads relative to the other factors. One explanation for the lack of impact for psychosocial factors may be the relatively large impact of personality. The large role of personality may potentially reflect differences in individual response to the work condition and may account for similar variance in spine loading as the psychosocial factors. 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 physical factors.

The change in the relative contribution across the models may be an indication of the complex relationship between 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 upon 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 impact of gender and other factors on spine loads.

In order to have a good appreciation of the current results, several potential limitations must be addressed. First, the independent variables had only a few levels (e.g. two), thus, limited variability may under-represent the impact of these variables. Basically, the models used dichotomous variables to predict continuous responses. In addition, the relative importance of the variables may be dependent upon the levels selected. In other words, the lack of importance of the psychosocial factors may have been due to the environment selected with more complex mental demands potentially having larger impact on the responses and loads. Furthermore, task asymmetry may also have a greater impact with additional levels (e.g. 45^{o}). Second, 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. A more adjustable work environment may have decreased the importance of anthropometry relative to the other factors.

CONCLUSION

The study results indicate box weight, placement control, individual's anthropometry, and to a lesser extent gender and personality directly impact the loads on the spine. 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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