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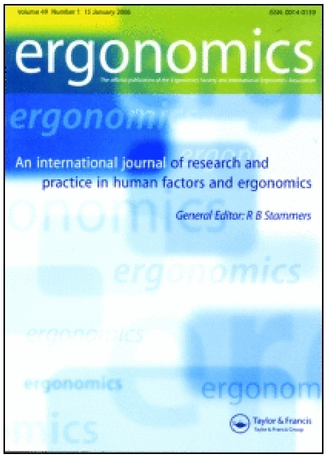

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The future of research in understanding and controlling work-related low back disorders

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Invited Plenary Paper

The future of research in understanding and controlling work-related low back disorders

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Our knowledge of low back disorder (LBD) causation has progressed well over the years with in-depth understanding accelerating in the traditional disciplines of biomechanics, psychology, psychophysics, psychosocial, physiology, genetics, organizational psychology and rehabilitation. However, each of these disciplines has studied LBD causality in isolation of other disciplines. The underlying assumption is that each discipline can fully explain causality and each discipline is treated as if it were mutually exclusive and exhaustive of the other disciplines. Hence, the body of knowledge has progressed along research silos where we have in-depth knowledge along given research tracks that are defined by the boundaries of the discipline. Furthermore, a wealth of knowledge has been amassed within each of these research silos. How can they all be correct if they are indeed mutually exclusive and exhaustive? The answer is: they cannot be. This brief review of the state-of-the art in LBD research applied to ergonomics, suggests that instead of observing LBD through the myopic lens of each discipline, we need to begin to view LBD causality as a system. Recent work attempting to understand the interaction between these traditional disciplines has demonstrated that many of the findings along these silos are really interrelated and can be explained in terms of changes in the biomechanical loading at the tissue level. It is argued that further efforts to understand these interactions represent the next level of understanding causality of LBDs.

Keywords: Low back pain; Low back disorders; Biomechanics; Musculoskeletal disorders; Causality; Work effects; Cumulative trauma; Risk assessment

1. Introduction

Low back disorders (LBDs) continue to represent a very common and costly problem for industry that are often associated with the workplace (Spengler *et al.* 1986, Webster and Snook 1994, Dempsey and Hashemi 1999, George 2002). Over the past several decades,

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the ergonomics and medical literature have reported thousands of studies that address the causality and control of LBDs. However, LBD reporting has changed little over the years. How is it that we are able to significantly increase our scientific knowledge base yet we are still unable to control risk?

This lack of impact may be due to several factors. First, part of this trend might be attributed to a lack of implementation of what is already known. Governments have been slow to incorporate ergonomics regulations in industry and, thus, much of the knowledge may never be implemented. Second, the workplace is a dynamic, complex environment that makes intervention studies difficult to implement and, therefore, makes the proof of ergonomics intervention benefits difficult to document. Third, perhaps the science base has missed a critical component of causality and, hence, our knowledge of causality might not be sufficient to control the problem. While arguments can be made for each of these factors, this discussion will focus on the last factor, that of the scientific voids that must be filled to advance the state of the art in LBD research and risk control.

Traditionally, the literature has investigated LBD causality via the traditional disciplines of biomechanics, psychology, psychophysics, psychosocial, physiology, genetics, organizational psychology and rehabilitation. Each of these disciplines has studied LBD causality in isolation of other disciplines. The underlying assumption is that each discipline can fully explain causality and each discipline is treated as if it were mutually exclusive and exhaustive of the other disciplines. Hence, the body of knowledge has progressed along research silos where there is in-depth knowledge along given research tracks that are defined by the boundaries of the discipline. Further, a wealth of knowledge has been amassed within each of these research silos. How can they all be correct if they are indeed mutually exclusive and exhaustive? The answer is: they cannot be.

Perhaps instead of observing LBD through the myopic lens of each discipline, we need to begin to view LBD causality as a system. Recently, the National Research Council (1999, 2001) has suggested a conceptual model of how the different avenues of research may be interrelated. Figure 1 suggests how the various potential risk factors associated

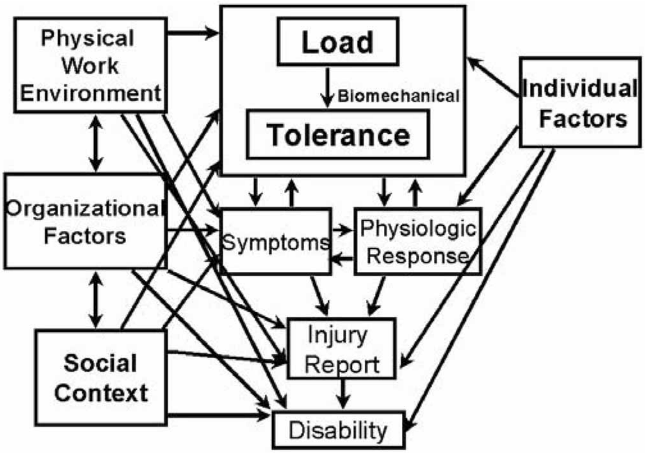

Figure 1. Conceptual model of how physical factors, organizational factors, social context and individual factors affect the load tolerance relationship and subsequent responses for the low back.

with these various research disciplines may be interrelated. The premise underlying this conceptual model is that any LBD must have a biologically plausible foundation. In this model, the biomechanical load-tolerance relationship represents the underpinning or root cause of a LBD event. McGill (1997) proposed that injuries and disorders are initiated when a biomechanical load imposed on a tissue exceeds the tissue tolerance. This situation can occur when loads become excessive, as when heavy objects are lifted or when the tolerance has decreased, such as occurs through ageing or cumulative trauma. Figure 1 also shows that this load-tolerance relationship can be impacted through various mechanisms that have been reported in the various research disciplines. For example, physical work factors can influence the magnitude and nature of the loading occurring on the spine. Similarly, psychosocial factors and organizational factors might cause muscle recruitment patterns to change and increase loading on spinal tissues. In addition, tolerance may be affected by individual genetic and psychological factors as well as through previous loading history (cumulative trauma disorders (CTD) or adaptation). Each of these factors can either lower or raise the tolerance to loading and can, therefore, influence this load – tolerance relationship.

Figure 1 also indicates how psychological factors may play a role in LBD findings. The diagram indicates that the load – tolerance relationship initiates a sequence of events relating to potential low back pain symptom perception and reporting. This sequence of events indicates that reporting and perception can be influenced by a multitude of psychological and perceptual factors. However, these reports and perceptions are also the root source of information for some research disciplines (i.e. epidemiology). Hence, whereas, the field of biomechanics derives its findings from the actual load – tolerance relationship, observational disciplines, such as epidemiology, derive their findings from derivatives of this load – tolerance relationship (reporting), which might be influenced by personal factors, motivations, perceptions and altered pain thresholds. Therefore, this conceptual model suggests that the different disciplines are really looking at the same injury causality process, but these different disciplines are simply observing different aspects of the process.

Conceptualizing the LBD causality process, as indicated in figure 1, also suggests promising avenues for accelerating the understanding of causality. The conceptual model indicates that the load – tolerance relationship can be influenced by many factors. However, there is a void in the literature in that it is not known how many of the factors outside of the biomechanics silo influence the load – tolerance relationship. Hence, it is the contention of this treatise that the future of research into LBD causality lies in understating the interactions between biomechanics and these other research silos. This paper will review the current studies that have begun to explore this vast void in understanding.

2. The evolution of accurate assessment tools

Perhaps one reason why more progress has not been made in understanding how the various risk factors interact with biomechanical loading is that, until recently, the assessment techniques capable of assessing the response of the human body to non-physical risk factor influences have not been in place. Historically, most biomechanical models used in ergonomics have made limiting assumptions about the musculoskeletal response to conditions under which work is performed. Traditionally, models have been deterministic in that given an external load imposed upon the spine during work, the muscular response required to precisely counteract the external load is calculated and the impact of that muscular response on spinal loading is determined specifically. However, in the human body, significant variation in muscle recruitment to realistic work activities is present, which can significantly alter the nature of the loading on spinal tissue. Traditional deterministic models are unable to account for the collective influence of the trunk muscle system (co-activation) that both supports the external load and simultaneously uniquely defines three-dimensional spinal loading for a given individual under a given situation. Ignoring co-activation is undesirable in that the estimates of spine compression could be under-predicted by 45% and estimates of spine shear loading could be underestimated by as much as 70% (Granata and Marras 1995b). These limiting assumptions have made these models unable to appropriately evaluate three-dimensional spinal loads that occur during realistic dynamic exertions as well as under situations that would solicit muscle co-activation such as are expected to occur in response to non-physical risk factors. Proper assessment of three-dimensional spine loading has been found to be important in the proper assessment of disc injury (Natarajan *et al.* 1994). Deterministic models are also problematic in that they are not able to account for the variability in muscle recruitment and the subsequent variability in spine loading that occurs as a function of a particular individual or from trial to trial during repetitive lifting bouts.

Many of these issues have now been resolved with the advent of biologically assisted biomechanical models (McGill and Norman 1986, Marras and Sommerich 1991a,b, McGill 1992, Granata and Marras 1995a, Marras and Granata 1995, 1997b,c,). Over the past decade, efforts in the author's laboratory at the Ohio State University have been focused on developing a realistic, dynamic, electromyography (EMG)-assisted biomechanical model (Ohio State University (OSU) biodynamic EMG-assisted model) that is physiologically and biomechanically accurate (Marras and Sommerich 1991a,b, Granata and Marras 1993, 1995a, Marras and Granata 1995, 1997a,b,c,). This model has employed magnetic resonance imaging technology to more accurately account for the muscle lines of action (Jorgensen *et al.* 2001), muscle cross-sectional area (Marras *et al.* 2001c) and influences of gender on spine loading (Marras *et al.* 2002, 2003). These EMG-assisted biodynamic models have been thoroughly evaluated and validated (Granata *et al.* 1999, Marras *et al.* 1999e). Hence, these models have made it possible to examine the body's specific biomechanical response to a wide variety of stressful situations. While numerous studies have explored spine loading in response to changes in physical workplace characteristics (Marras and Davis 1998, Marras *et al.* 1999a, 1999b, 1999c, Ferguson *et al.* 2002), only recently have biomechanical studies begun to explore how spine loading responds to the interaction between an individual's characteristics, cognitive processing and physical demands during the performance of work.

3. The action is in the interaction

The biologically-assisted models described above have made it possible to assess the biomechanical response of the human body to the non-mechanical risk factors described in figure 1. Hence, for the first time it has been possible to quantitatively assess the interactions among risk factors in terms of defining the spine load – tolerance relationship and potential LBD risk.

3.1. How do psychosocial factors impact spine loading?

The first study to describe how the body responds to these diverse influences was reported in 2000 (Marras *et al.* 2000). The psychosocial literature had reported for years that psychosocial influences were an important factor for LBD risk (Bigos *et al.* 1991, Bongers *et al.* 1993, Burton *et al.* 1995, Davis and Heaney 2000, Hoogendoorn *et al.* 2000, 2001, Krause *et al.* 1998, van Poppel et al. 1998). However, the causal mechanism was poorly understood. Some speculated that poor psychosocial environments would create an environment where workers were more likely to report injury and illness. However, studies in the author's laboratory have been able to demonstrate a complex biomechanical pathway through which psychosocial risk factors act. One study (Marras *et al.* 2000) asked subjects to perform standard lifting tasks under psychosocially stressed and unstressed conditions. In this study, psychosocial stress was defined as the interaction of the experimental subject with the experimenter. Under the unstressed conditions, the experimenters were friendly and interactive with the subjects during the lifting exertions. During the stressed conditions, the experimenters were terse and agitated. Even though the same exact physical exertions were performed under both conditions, the stressed conditions resulted in slightly greater spine loadings, which were traced to greater trunk muscle coactivity (figure 2). However, further analysis revealed that individual responses varied dramatically to the stress conditions (figure 3). These individual responses were tied to individual personality characteristics that interacted strongly with psychosocial stress. In particular, those subjects who were classified as introverts via the Myers-Briggs personality inventory experienced a 14% increase in spine compression and a 27% increase in lateral spine shear under the stressed conditions compared with their extravert counterparts, who experienced far less increases in spinal load (4–6%) under the stressed condition. Similarly the intuitor personality trait was associated with much greater spine loading (10–25%) responses under the stressed conditions compared with negligible increases in spine loading experienced by the sensor counterparts. Hence, this study has shown that interactions between individual factors (personality traits) and psychosocial stress are able to explain much of the variability in subject response when performing physically demanding tasks.

In a similar manner, more recent studies have been able to show how the degree of mental processing and pacing required during a physical task interact to strongly

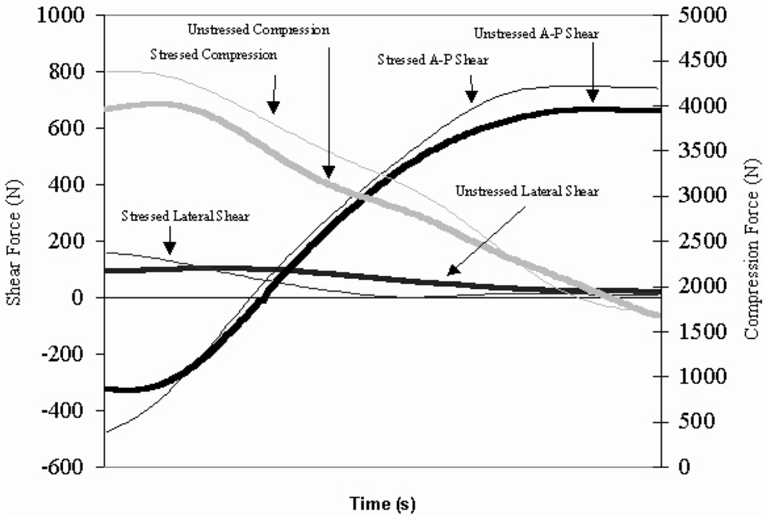

Figure 2. Representative data for the three-dimensional spinal loads for an unstressed and stressed lift.

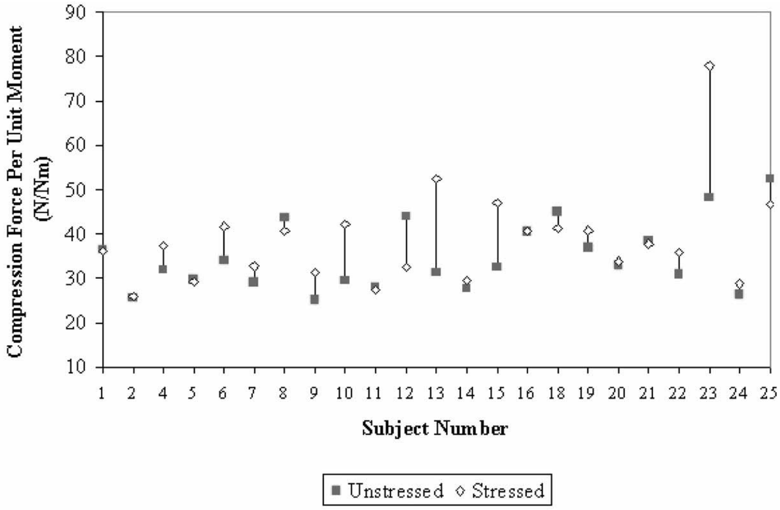

Figure 3. The maximum compression force per unit of sagittal trunk moment for each of the subjects during the unstressed and stressed conditions.

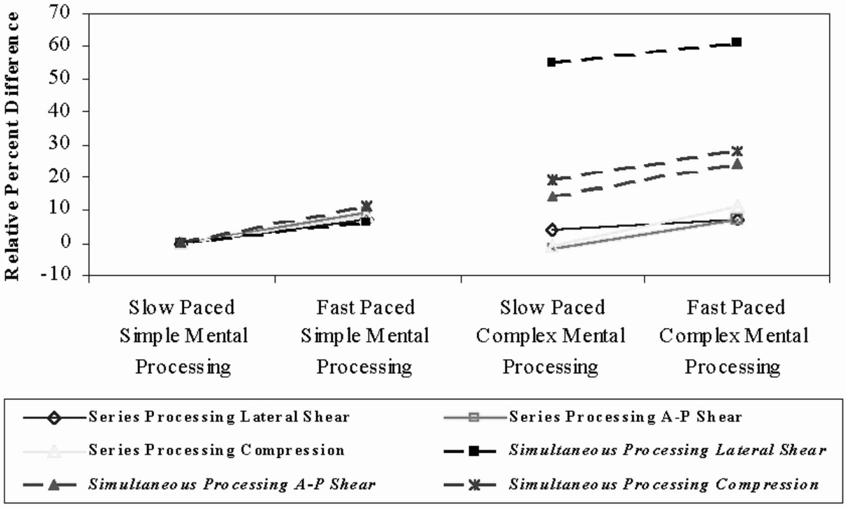

Figure 4. Impact of series and simultaneous mental processing on the spinal loads. Values are relative to the simple mental demanding task at the slow rate.

influence biomechanical loading of the spine (Davis *et al.* 2002). In this study subjects were asked to perform lifting tasks under fast and slow pacing conditions while the mental processing requirements were altered. Mental processing consisted of high or low decision-making tasks as well as varying levels of object placement complexity. Pacing by itself did not have much of an influence on spinal loading. However, when task complexity was great and high levels of mental processing were required, these factors interacted with pacing to increase spinal loading by 25 to 65% (figure 4). Here again, the mechanism of loading was traced to significant increases in muscle co-activation.

3.2. How do individual factors affect spine loading?

Perhaps one of the more challenging issues in the control of LBD in industry is identifying who will get LBD and how it relates to the tasks they are required to do? While some studies have investigated how the tolerance of the spine changes as a function of individual factors (Koeller *et al.* 1986, Jager *et al.* 1991, Mayer *et al.* 2001), few have explored the interaction between individual factors and spine loading.

Recent studies in the author's laboratory have attempted to discover how loading of the spine might interact with those who have a history of back pain. This is important, since many patients return to work while still experiencing pain. It has been well documented that one of the strongest predictors of future LBD is a previous history of LBD (Smedley *et al.* 1997, van Poppel *et al.* 1998b). A recent review of LBD risk factors found that 80% of the studies reviewed concluded that previous history of LBD was associated with an increased risk of symptoms (Ferguson and Marras 1997). It has also been reported that the more frequently back pain occurs, the greater the risk of new back pain. Specifically, van Poppel *et al.* (1998a) reported that the odds ratio was 9.8 for new episodes of LBP in those material handlers reporting back pain more than twice in a year. However, it is unclear whether reports of 'new episodes' in these studies were truly new or reoccurrences of previous episodes. One might speculate that patients who do not fully recover from a LBP episode might be predisposed to further exacerbation of a LBP event.

A recent analysis of the Washington State Workers' Compensation data indicated that gradual onset (chronic) back injuries represent two-thirds of the award claims and 60% of lost workdays attributed to back injuries (National Research Council 2001). Likewise, a recent analysis performed on low back-related workers' compensation claims in Ohio indicated that 16% of the back injuries accounted for 80% of back injury costs. Further evaluations suggested that 'these high cost back injuries often result from re-injury of an existing condition' (Hamrick 2000). Hence, it appears that recurrent low back injuries could represent a rather large and costly problem. These high cost situations represent an opportunity for employers to realize the benefit of ergonomics design, since they are already paying the cost of the injury. Ergonomists must help employers to realize that it makes little sense to return a LBD injured worker to the same job that might be responsible for the initial injury. Thus, it is important to correctly design workspaces for those returning to the workplace from a musculoskeletal disorder. However, it must be understood how a specific individual's LBD (individual factor) might interact with the work to change the loading on the spine and, thus, increase the risk of a recurrent LBD.

The author's first study of spine loading in those with LBD compared 22 patients with LBD to 22 asymptomatic individuals as they lifted from six different lift origins in the sagittal plane (Marras *et al.* 2001). The EMG-assisted modelling procedure was adjusted so that EMG calibrations would be made on those with LBD (Marras and Davis 2001, Marras *et al.* 2001). This procedure was important since most EMG-assisted models must be calibrated with maximum subject exertions. However, since LBD subjects are unwilling or unable to produce maximum exertions, the EMGs must be calibrated by an alternative method if the model results are to be valid.

The results of this study indicated that, when the exact same lifting exertions are performed, those with LBDs experience 26–75% greater spine loading than their asymptomatic counterparts. A large degree of kinematic compensation was also observed. LBD patients attempted to minimize the external moment to which they were exposed and, thus, minimized postural deviations compared to asymptomatic subjects. However, this behaviour resulted in over 50% greater antagonistic co-activation in the

LBD group. This co-active muscle compensation resulted in a situation where spine compressive and anterior/posterior (A/P) shear loads were not only markedly greater in the LBD group but also dependent upon the lift origin location (figure 5). Thus, this study indicated that for the first time spine loads were much greater in those suffering from LBD. Furthermore, figure 5 indicates that proper ergonomics design of the workplace is even more important for those suffering from LBD because spine loading is exacerbated in all lifting locations.

A more recent study (Marras *et al.* 2004) has compared the biomechanical loading of 61 LBD patients with 62 asymptomatic subjects along with kinematic measures of trunk status. In this study, subjects were asked to lift from various lift origins in asymmetric locations. As with the previous study, significant increases in spine loading were noted in those suffering from LBDs. However, the increases in spine loading in those suffering from LBDs were greater for lifts occurring in the clockwise direction compared to the counter-clockwise direction. Here, once again, greater spine loading was tracked to the increased antagonistic co-activity occurring in those suffering from LBDs.

Trunk muscle antagonistic co-activity not only increased spine loading, it also reduced kinematic performance in a pre-test designed to measure the extent of a LBD (Marras *et al.* 1995, 1999). Previous studies have demonstrated that those with more severe LBD have greater quantifiable kinematic impairment (Marras *et al.* 1995, 1999). This biomechanical study attempted to predict spine loading for individual LBD patients given the degree of kinematic compromise. Under realistic symmetric and asymmetric lifting conditions, the degree of kinematic compromise was related to the degree of spine loading increases in those with LBP. Those with greater kinematic compromise employed greater levels of antagonistic muscle co-activation that resulted in increases in spine loading. Given the degree of kinematic compromise and the lifting task conditions, the increase in spine loading above that of an asymptomatic individual could be estimated. Analyses indicated that 72% of the variance in spine compression could be predicted given the kinematic profile of the subject. Thus, this effort represents the first study to

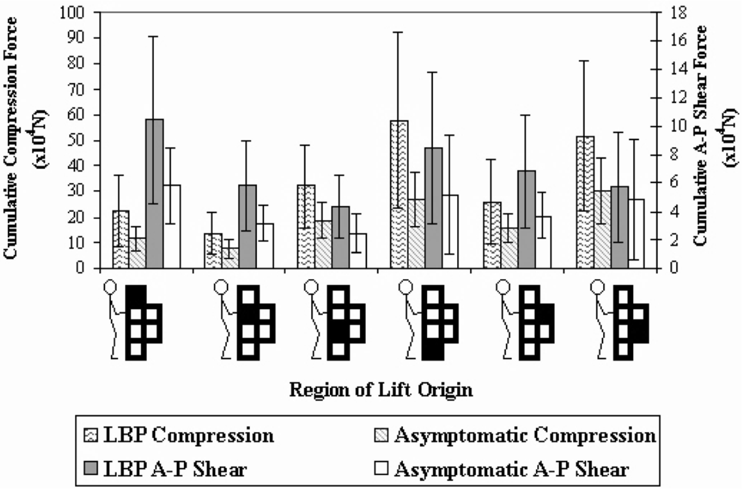

Figure 5. Cumulative compression and anteroposterior shear forces for individuals with low back pain and asymptomatic individuals as a function of lift origin as identified by shaded box.

quantify the increases of spine loading expected in a worker suffering from LBD, given their degree of LBD impairment. This information has made it possible to better design workplaces while taking into account the interaction of individual LBD status and the physical demands of the job.

A recent study (Marras *et al.* 2002) has explored the influence of gender on mechanical loading of the spine. Prior to this study, no biomechanical study has attempted to quantify and understand how differences in anthropometry between genders might influence muscle recruitment and subsequent spine loads. Because the modern workplace seldom discriminates between genders in job assignments, it is important to understand how differences in spine loading and potential LBD risk might be associated with gender differences. In the study, 140 subjects participated in two separate experiments requiring different degrees of musculoskeletal motion control during sagittal plane lifting. Subjects were asked to lift under conditions where motion was isolated to the torso in the first experiment. Whole-body free-dynamic lifts were performed in the second experiment. As in the previous studies, the OSU biodynamic EMG-assisted model was used to evaluate spine loading under these conditions. The results indicated that absolute spine compression was generally greater for the men. The controlled (isolated torso) conditions indicated that most differences were attributed solely to differences in body mass. However, under whole-body free-dynamic conditions, significant differences in trunk kinematics and muscle co-activations resulted in greater relative compression and anterior–posterior shear spine loading for the women. A significant gender by velocity interaction was also noted. Spine loadings were up to 20% greater for females when the torso was moving up to 45° per s. Since trunk kinematics are often defined by the work task, this result indicates specific conditions where risk might be particularly great for women. Hence, even though men would be expected to have greater spine loading because of their greater body mass, under realistic occupational lifting conditions women actually experience greater loading because of the way they compensate, kinematically, for the lifting situation. When spine tolerance differences are considered as a function of gender (Jager *et al.* 1991), one would expect that females would be at even greater risk of musculoskeletal overload during lifting tasks. The results indicate the need to account for differences between the genders when designing the workplace.

3.3. How can low level exertions lead to low back disorders?

Perhaps one of the more challenging issues for ergonomists is to understand and quantify the impact of low level exertions on the risk of musculoskeletal disorders. In particular, prolonged work at computer workstations is suspected of increasing risk. Yet few have been able to address the causal mechanism behind such disorders. An exploratory study in the author's laboratory has recently been able to make some progress in this area. The underlying premise of this study is that low level exertion problems are associated with the development of myofascial trigger points (Mense *et al.* 2001). This study has explored the potential interactive effects of postural and visual stress on the development of trigger points in the upper back. Twenty participants were subjected to four different conditions consisting of high or low combinations of visual and/or postural stress. Subjects were checked for the presence or absence of trigger points both before and after each experimental session. Surprisingly, visual stress appears to interact strongly with posture to create conditions conducive to the development of trigger points, whereas visual stress or postural stress by themselves had little effect on the development of trigger points.

4. Application of the knowledge base

How can we most effectively apply research findings to the design of work? One significant problem facing the ergonomics community is that there are not enough well-trained ergonomists available to fill the need. Even worse, many industries fail to recognize that they need a well-prepared ergonomist to assist in their workplace or product design. Since efficient and effective ergonomic design occurs in the design stage, the design responsibility often lies with the design engineer. Until qualified ergonomists are incorporated into this process the best attack point to ensure ergonomic design occurs is with the workplace design engineer.

Design engineers rely heavily on computer-aided design software to help perform their job. One strategy is to provide these designers with software that incorporates ergonomics principles so that ergonomics considerations are embedded in the designs. Professor Don Chaffin at the University of Michigan has made significant strides in providing software designers with human motion information that can be incorporated into digital human model software. This information is going a long way towards ensuring that the software considers the realistic dynamic motions capabilities of the workforce in the design of workspaces.

In order to ensure worker health, efforts such as these must continue to develop and must begin to incorporate not only motions, but valid and reliable indicators of musculoskeletal stress that can be used to warn the designer of risk associated with a workplace design. Much of the contemporary literature (Granata and Marras 1995b, 1999, Marras and Granata 1997b) has demonstrated the value of biologically assisted models in accurately describing three-dimensional loading on the spine. Yet, incorporating such information into predictive models used in design has been problematic, since there is no actual person from which to collect biological information. Recent efforts on the part of Professor Karwowski at the University of Louisville in conjunction with the Biodynamics Laboratory at the Ohio State University have developed a methodology to overcome these issues. Current efforts are using neuro-fuzzy logic approaches to model muscle activities in response to physical and cognitive workplace parameters (Lee *et al.* 2000, 2003). Current efforts are in the process of developing biomechanical model engines that can predict the co-activity of the trunk musculature given the physical work situation and the workers' perception of the situation. These drivers can be used to dictate joint load and, thus, risk associated with the interactions between risk factors. It is envisioned that these engines will one day feed human digital models so that the variety of biological responses and spine loading expected from a workplace situation can be appreciated.

These models must continue to evolve and strive to incorporate as much realism as the knowledge base permits. In order to truly understand the effects of risk factor interactions, these models must not only include muscle co-activation but must also begin to incorporate the effects of other biomechanical modifiers. While the array of trunk muscle forces help play a large role in defining instantaneous spine loads, it is known that fatigue, cyclic loading and duration of loading also play a major role in risk. Recent work has indicated the importance of the ligamentous system in defining spinal loads under these time-dependent conditions (Solomonow *et al.*1999, Solomonow and Krogsgaard 2002). Recovery time due to ligament hysteresis has been shown to be as long as 24 h when lifting in flexed postures (Solomonow *et al.* 2000, 2001).

Stability criteria have also been demonstrated as significant issues in trunk muscle behaviour and task performance (Panjabi, 1992, Solomonow *et al.* 1999, Cholewicki *et al.*

2000, McGill *et al.* 2000, Granata and Wilson 2001). The risk models must assess how stability modifies or exacerbates risk during work.

This brief discussion has indicated that LBD causality is a multi-dimensional issue that can be influenced by many dimensions of the workplace. The key to effective assessment and control of risk in the workplace is the development of interfaces that can be used by those who design the workplace. These designers are not necessarily researchers or ergonomists who understand the science. Hence, it is incumbent upon the research community to provide valid, reliable tools that can impact the risk of LBD at the worksite.

5. Future needs and trends

Finally, in order to understand and control LBD risk in the workplace, it needs to understood how the work environment and the worker are changing and how to make appropriate changes to the risk models. In terms of the work, it has changed dramatically and will continue to change. First, manufacturing is on the decline in the USA and will continue to decline. As of today, manufacturing represents less than 16% of its economy. Much of the manufacturing jobs have moved across the border and the products are simply moved from place to place in the USA. That is not to say that ergonomics interventions are not needed in the countries where manufacturing is occurring. However, it does represent a shift in the activities of American workers. Risk models developed using data from manufacturing facilities may not be appropriate for understanding risk in service industries. A recent evaluation found that the work profile has changed dramatically in that loads currently lifted are about half as heavy as previously recorded, but lifted with twice the frequency (Dempsey 2003). Hence, the total work done has not changed, but the nature of the loading cycle has. This indicates a need to better understand how to quantify the effects of cumulative trauma.

Hence, the nature of work and the profile of the worker are changing. Work is increasingly low force yet high repetition. Workers are increasingly overweight, older and unconditioned. Thus, issues of optimal health have changed over the years. Research efforts must keep pace with these changing societal trends. .

6. Conclusions

This brief review of recent studies exploring the interaction between physical factors and other risk factors has indicated that there is often a strong biomechanical pathway associated with those variables that were previously thought to be psychological or inherent risk factors. Modern assessment techniques, such as EMG-assisted models, have the sensitivity and robustness to detect the effects of these interactions. Many of these interactions can explain the variance associated with observational studies. Through continued consideration of risk interactions, models and understanding of LBD causality will continue to improve. Future efforts must incorporate this understanding into digital human models and data bases so that these findings can be easily understood by the designers of work.

7. Prescription for future of ergonomics

Consider the whole picture. The action is in the interaction. Potential risk factors must not be ignored and the world should not be looked at myopically simply because it does not fit the traditional view of LBD causality. Understanding will evolve through scientific, quantitative studies that can assess how much exposure is too much exposure for a given situation.

An underpinning of science must be demanded. An understanding of causality must be the goal and ergonomics logic that does not fit into the understanding of causality must not be accepted. The challenge must be to get it right and be self-critical. The ultimate user of the research must be considered. Workplace designers and product designers are often not ergonomists.

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