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Occupational low back disorder causation and control

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Low back disorders (LBDs) continue to be the most common musculoskeletal problem in the workplace. It affects many workers, is associated with high costs to industry and the individual, and can negatively influence the quality of life for the workers. Currently there is significant controversy about the work-relatedness of LBD and the ability of ergonomics interventions to control the problem. This paper systematically examines the body of knowledge associated with LBDs and considers how information from different disciplines of study collectively might be used to assess the causality and control of LBD due to physical factors associated with work.

1. Introduction

Consider the paradox presented by Deyo (1998): 'The American economy is increasingly post industrial, with less heavy labour, more automation and more robotics, and medicine has consistently improved diagnostic imaging of the spine and developed new forms of surgical and non-surgical therapy. But work disability caused by back pain has steadily risen'. Implied in such a statement is the suggestion that the heavy lifting is the sole indicator of work-related low back pain. Such statements causes one to pause and question what is known about the process of low back pain. Is there more to work-related low back pain than reducing the weight of the object lifted? Does the increase in psychological pressure in the workplace relate to this increase in back pain? Has the workplace changed in other ways not understood? All these issues lead one to question the quality of the knowledge relating the causal factors associated with low back disorder (LBD). The objective here was systematically to examine the components of the knowledge base associated with the causality and control of work-related LBD and to identify opportunities for advancement of this knowledge base.

2. How big of a problem are work-related low back disorders?

LBDs represent the most common and most costly musculoskeletal disorder experienced in the workplace. Up to 80% of adults will eventually experience back pain at some time during their life and 4–5% of the population has an acute low back pain episode every year (Plante *et al.* 1997), which indicates that in the USA alone an additional 11–13 million people will develop LBDs annually. Much of this LBD is associated with occupational factors (Spengler *et al.* 1986) and significantly increases workers compensation costs. For example, LBDs account for ~16–19% of all worker compensation claims, but 33–41% of the total cost of all work compensation costs (Webster and Snook 1994, Spengler *et al.* 1986).

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Treatment varies for LBD around the world, but it is known that in the USA more back surgery is performed than in any other country. Differences in surgery rates also exist between regions of the country (Andersson 1997). Estimates of annual costs for LBD have been as high as US$100 billion. Manual material handling (MMH) tasks have been associated with the majority of lower back injuries (Snook *et al.* 1978, Bigos *et al.* 1986). Surveillance studies have shown that those who handle materials are at a much greater risk of LBD than those who work in occupations that do not require lifting (Andersson 1997). Thus, LBDs are at epidemic level and they continue to be one of society's most significant non-lethal medical conditions.

3. Who is at risk?

One can learn much about the factors that are associated with increased risk of LBD by examining the epidemiologic literature. Several trends are apparent from this body of work. First, personal factors play a role in risk of experiencing a LBD. It is important to separate personal factors from occupational factors so that one can distinguish risk associated with work from that associated with individual characteristics. A review of 57 original industrial-based surveillance studies (Ferguson and Marras 1997) indicated that personal factors were the most frequently investigated risk factor for LBDs. Of these studies, previous back injury history and income were most often associated with risk (table 1). LBD typically begins at a relatively young age with the highest frequency of symptoms occurring between 35 and 55, while lost workdays typically increase with increasing age (Andersson 1997). Gender also appears to be an interactive factor in determining who experiences LBD. The risk for men peaks at ~40 years of age, whereas, the greatest prevalence and incidence for women occurs between 50 and 60.

Anthropometry has also been widely investigated as a personal risk factor. Although there is little consensus among studies, some have associated stature with

Table 1. Personal risk factor associated with low back pain (adapted from Ferguson and Marras 1997).

Personal risk factors	Total no. of studies	Percentage of studies finding relationship
Age	31	35
Sex	24	8
Pervious history	8	87
Intelligence/education	10	40
Duration of pain	1	*
Race	3	0
Number of years experience/seniority	7	14
Marital status	4	25
Household income/unemployment	6	66
Exercise/recreational activity	10	30
Smoking	9	44
Length of time off	1	*
Headache	2	*
Distance to work	1	*
Car ownership	1	*

*Few observations, therefore percentage not calculated.

greater risk of LBD while others have identified sitting height as a potential risk factor (Ferguson and Marras 1997). One study also found that obesity is associated with a greater risk of LBD (Deyo and Bass 1989).

Most studies have indicated that isometric strength, by itself, was not related to risk of LBD. However, when matched to the job requirements, strength is an indicator of risk (Chaffin and Park 1973). In addition, endurance strength appears related to symptoms of LBD. One study explored patient handling skill and found an association with risk (Videman *et al.* 1989). Another often reported risk factor was smoking. However, a more thorough analysis of the literature reveals that smoking was associated with symptom reporting but not increases in lost time (Ferguson and Marras 1997). Hence, there may be other, yet unidentified factors that confound this relationship.

This brief review indicates that some personal risk factors may indeed exist. However, the strength of these correlations was mild at best. In addition, these individual risk factors are beyond an individual's or society's control with the exception of factors such as smoking or obesity. Yet, it is important to understand how these personal factors increase risk so that one can develop a better appreciation for how they might interact in a system along with occupational risk factors.

4. Risk factors at work

Epidemiologic methods have been used to identify occupationally related physical risk factors in a variety of industries. Bernard (1997) and Hoogendoorn *et al.* (1999) performed critical reviews of many of these studies. Traditionally, most epidemiologic studies have investigated the risk contribution of: (1) heavy physical work, (2) lifting and forceful movements, (3) bending and twisting, (4) whole-body vibration and (5) static work postures. The critical reviews have found strong evidence of LBD risk association for the lifting and forceful movements, bending and twisting, as well as the whole-body vibration risk factors. More moderate evidence or risk association was identified for heavy physical work. The literature was not able to support a relationship between static work postures and LBD (table 2).

Another potential occupationally related risk factor that has gained recognition over the past decade is that of psychosocial factors. Reviews by Davis and Heaney (2000) and Bernard (1997) indicated that factors such as job dissatisfaction, monotony of work, limited job control, and lack of social support were the most commonly identified potential risk factors. Although several studies have identified these issues as related to the risk of LBD, Davis and Heaney (2000) point out that

Table 2. Evidence for causal relationship between physical work factors and musculoskeletal disorders (adapted from Bernard 1997).

Body part *Risk factor*	Strong evidence (+ + +)	Evidence (+ +)	Insufficient evidence (+ /0)	Evidence of no effect (–)
Back				
Lifting/forceful movement	✓			
Awkward posture		✓		
Heavy physical work		✓		
Whole body vibration	✓			
Static work posture			✓	

none of these studies have properly simultaneously evaluated physical work risk factors. Consideration of biomechanical influence can have a significant impact upon the strength of the psychosocial factor findings. Table 3 indicates a 20% increase in null results of psychosocial factors when the studies control for biomechanical demands. Thus, it has been impossible to separate the contributions of the physical workplace from that of the psychosocial components of the work.

One inherent problem associated with many epidemiologic studies is that, since most studies observe whether a potential risk factor is present or not, it is difficult to determine the level or magnitude at which the presence of a risk factor becomes problematic. Very few field studies have employed biomechanical exposure metrics with the degree of sensitivity necessary to quantitatively evaluate the precise relationship between LBD risk and biomechanical variables. The first such studies were performed by Marras *et al.* (1993, 1995) where, using a case-control design, they quantitatively monitored 114 different workplace variables in >400 jobs that were classified according to historical risk of LBD. Figure 1 shows how quantitative exposure measures were collected at the work site. These analyses showed that many, previously unexplored biomechanical workplace factors (such as trunk velocities) were associated with risk. However, when a multivariate logistic model of risk was considered, five factors in combination (lift frequency, sagittal torso bending angle, lateral velocity, twisting velocity and external load moment), described the relationship with risk of reporting a LBD incidence (OR = 10.7) and LBD lost or restricted time (OR = 10.6) very well. This study, for the first time, described the multidimensional nature of biomechanical risk at the workplace, and also provided a means to quantitatively describe how much exposure was too much exposure to a combination of biomechanical risk factors. More recently Norman *et al.* (1998) confirmed and built upon these findings while considering the cumulative loading occurring at the workplace. They produced significant odds ratios using four biomechanical risk factors (moment, hand force, peak shear force at L4/L5, peak trunk velocity). This study was also unique in that it found that these findings held even when controlling for psychosocial risk factors.

In addition, in a review of previous occupationally related epidemiologic studies, Ferguson and Marras (1997) demonstrated that the findings of epidemiologic studies vary greatly depending upon the dependent measure observed (e.g. discomfort versus incidence versus lost time, etc.) (figure 2). In addition, with most epidemiologic studies it is difficult to investigate the interaction among potential risk factors. This is particularly true given the variable nature of the modern workplace. Hence, although epidemiologic studies can provide valuable insight as to which risk factors might be associated with risk of LBD at the workplace, the depth of the information is not of the quality that would be sufficient for control of the risk on the job.

Control of risk in the workplace requires knowledge beyond simple identification of risk factors. It requires a much deeper understanding of how risk of LBD occurs at the workplace. Practically, one's knowledge can only develop to this state when one can quantify the means by which risk is increased. One's understanding also needs to progress to the point where one can begin to understand why some people are at greater risk of developing LBD than others. In other words, one needs to begin to develop a better understanding so that the variability between individuals can be better understood. Only then can one answer the question: how much exposure to risk is too much exposure to risk for an individual?

Table 3. Percentage of studies reviewed and relationship with psychosocial variables evaluated as a function of controlling for biomechanical variable (B) or unadjusted for biomechanics (U) (adapted from Davis and Heaney 2000).

Psychosocial variable	Low job satisfaction		Lack of variety and skill		Lack of influence over work		Poor social relations		Poor supervisor relations		Poor co-worker relations		High concentration demands		High work demands		High respons-ibility		High feeling of stress		Multi-component variables	
	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B	U	B
Positive association	50	35	32	20	33	13	18	20	30	17	22	0	36	50	47	36	33	0	50	40	54	18
Negative association	0	6	0	0	0	0	0	0	0	0	11	25	0	0	0	0	0	0	0	0	0	0
Null association	35	53	50	60	46	80	53	60	60	67	56	75	46	33	37	64	67	100	20	40	31	64
Positive and null association	14	6	18	20	21	7	29	20	10	17	11	0	18	17	16	0	0	0	30	20	15	18

These authors used a case-referent design.

Figure 1. Lumbar motion monitor (LMM) used for quantitative exposure assessment.

Occupational risk control requires tools that have high levels of both sensitivity as well as specificity. Given today's highly competitive industrial society, one can ill afford to incorporate control measures that do not have both high sensitivity and specificity. Tools intended to control occupational LBD that are not sensitive will not be able to identify those work situations that would increase the risk to the worker. Tools that are not specific may needlessly indicate that work situations need to be changed even though risk is not present. Such tools would waste valuable resources without justification. Recent studies have shown that the current LBD risk control tools need to be further developed (Marras *et al.* 1999, Waters *et al.* 1999).

5. Pathways to low back disorders

If one is to develop an appreciation for the mechanisms of LBD causality, as well as developing an effective means to control LBD at work, it is necessary to understand, physically, how back pain occurs. If mechanical workplace factors are indeed related to the risk of LBD, one would expect to identify certain pathways whereby loading of a tissue would result in the sensation of pain. Since a specific diagnosis cannot be made in >70% of patients with chronic low back pain, it has become fashionable in the medical community to address the behavioural aspects of low back pain (Bogduk 1995). The inability to detect anatomical sources of pain should not be surprising,

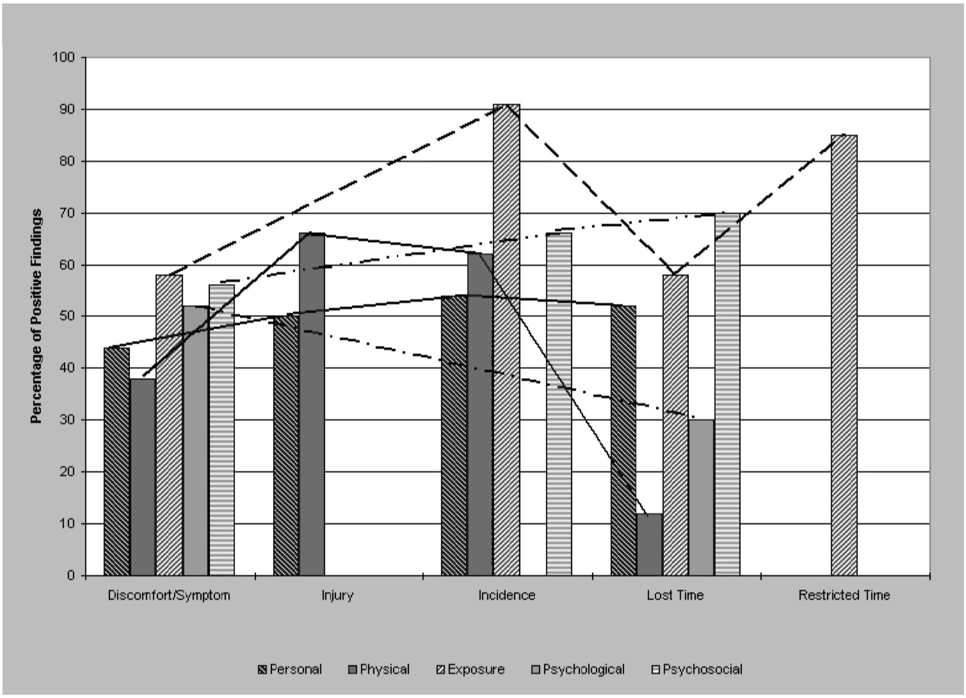


Figure 2. Percentage of positive findings and trend lines on all epidermiologic studies for each surveillance measure and risk factor combination. Note the increasing percentage of positive findings as the surveillance measure moves from discomfort/symptoms to incidence.

since most diagnoses are based upon static imaging of the spine while the patient is lying flat on a table, whereas structural strain would be expected to occur throughout a functional motion.

Literature exists that has identified anatomical sources of pain in the low back. Cavanaugh *et al*. (1997) functionally studied the cellular and neural mechanisms that can lead to facet pain, discogenic pain and sciatica. In the facet joint they have identified a system of nerve fibres and endings, nerves containing substance P, mechanoreceptors, and nerves in the facet joint and surrounding muscle that respond to inflammatory or analgesic chemicals. They have also identified nerve fibres and free nerve endings in the superficial annulus of the disc and small fibres and free nerve endings in adjacent longitudinal ligaments. These researchers have also explained how moderate pressure on the dorsal root ganglia can excite nerve fibres. Bogduk (1995) has also confirmed these sources of pain via investigations of anatomical innervations. However, he challenges the notion that muscles can be a source of chronic low back pain. Collectively, this information indicates that logical mechanical pathways exist that can help us understand how workplace risk factors might result in stimulation of pain sensitive tissue and LBD.

6. Biomechanical logic

Since it has been established that mechanical stimulation can explain how LBDs occur, one can further elucidate this relationship in more quantitative terms.

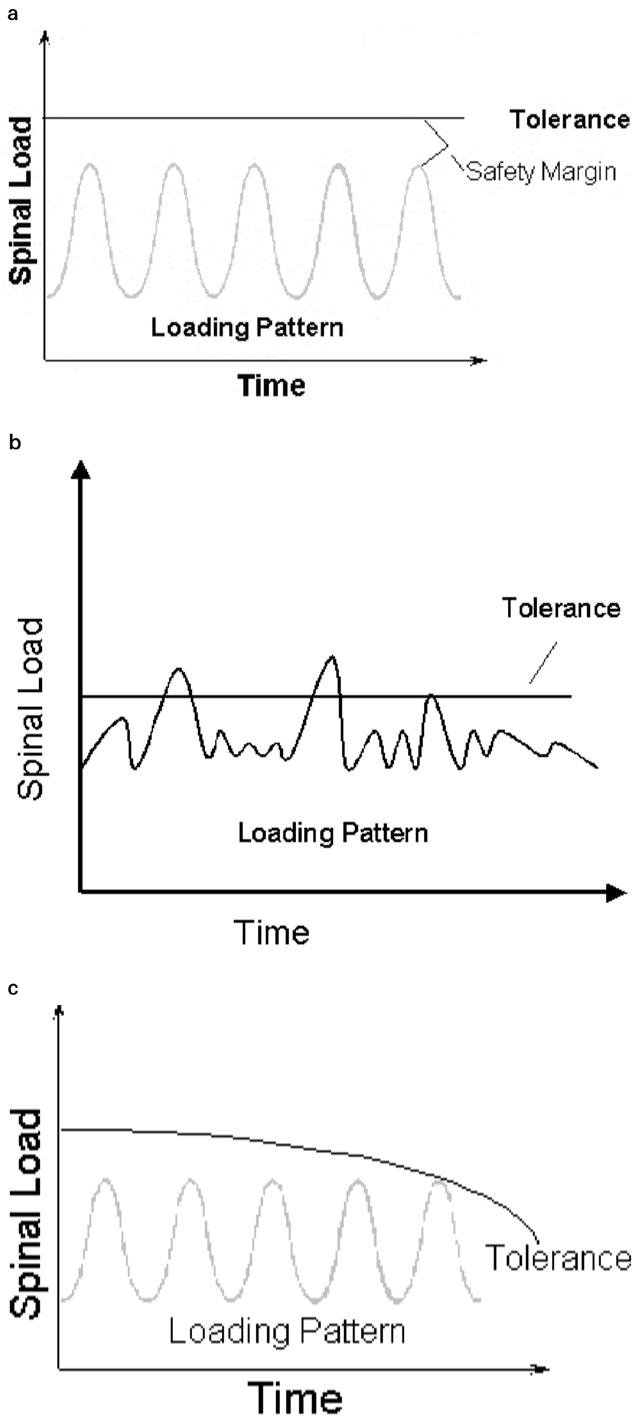


Figure 3. (a) Biomechanical logic. When a load exceeds a structure tolerance, injury occurs. (b) Biomechanical explanation for cumulative trauma due to increased variability in loading. (c) Biomechanical explanation for cumulative trauma due to tolerance reduction.

Biomechanical logic presents a mechanism by which one can quantify the loads imposed upon the spinal structure during a work task and can help one to address the issue of how much exposure is too much exposure (risk). Biomechanical reasoning is based on a load–tolerance relationship. This relationship assumes that during a work task, a load of a quantifiable magnitude is imposed upon the structures of the spine. As shown in figure 3a, if this imposed load is below the threshold for tissue damage, one would not expect an injury to occur. The magnitude of difference between this imposed load and the tolerance threshold for damage is known as the safety margin and can be quantified (McGill 1997). Repetitive tasks can also be described by this logic, however, under these circumstances the loading may become variable as indicated in figure 3b (Mirka and Marras 1993), the tolerance can decrease over time (figure 3c), or both can occur (figure 3b and c). Occupational biomechanical efforts to control risk are focused on the realistic evaluation of the applied load and/or the evaluation of the spine structure tolerance (Marras 1999).

6.1. *Spinal load assessment*

To understand better how the workplace observations of risk factors associated with LBD might relate to biomechanical logic, it is important that the assessments of spinal loading in the laboratory represent spine loadings that would occur at work in as realistic a situation as possible. Only then can the laboratory findings be validated by epidemiologic studies in the actual workplace. Until our biomechanical studies can be validated in the workplace, they are simply unproven hypotheses. Under realistic work conditions, loading of the spine occurs in three-dimensional dynamic space. Figure 4 shows the three types of forces or loading that can occur on the spine. Loading can occur in compression, shear, or torsion. In order to truly understand causality and control risk, assessments of spine loading must be capable of realistically assessing spinal loads that would be expected in the workplace.

Two types of forces are typically imposed on the spine. External forces represent those forces due to the effect of gravity acting on the object being moved as well as the worker's body. As shown in figure 5, external loads represent the mass of the object lifted. They can also represent the forces generated by the force of gravity acting on the workers' arms and torso. The second type of force imposed upon the body is internal forces. Internal forces are those forces imposed on the spine due to

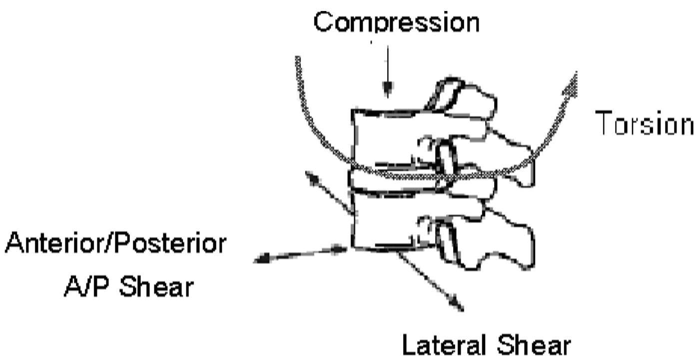


Figure 4. Three-dimensional loading occurring on the spine.

the reactions of the body to the external forces. Forces generated by muscles as well as passive forces in the connective tissue represent internal forces. However, as suggested in figure 5, the magnitude of the internal forces typically are much larger than the external forces since they must operate at a mechanical disadvantage.

The key to estimating accurately spinal loads is to account accurately for the internal loads needed to support the external loads. The sum of the internal and external forces occurring in three-dimensional space defines spinal loading. However, a major limitation has been the inability to accurately assess the loading due to the internal forces acting within the torso and imposing loads on the lumbar spine. For spine loading estimates to be accurate, they must assess internal forces in the torso under realistic work conditions that often involve whole-body free-dynamic lifting conditions.

Historically, researchers have attempted to estimate the activity of the internal forces generated by the trunk muscle through several methods. Early approaches assumed that a single equivalent muscle force in the back could represent the internal muscle forces. Stick figures with a single equivalent extensor muscle were used to assess the contribution of the trunk muscles to spine loading (Chaffin 1975). However, latter research identified the need to incorporate models capable of including multiple muscles to represent more realistically the complex reactions of the internal loading structures to external loads (Schultz and Andersson 1981). The neural activation patterns responsible for muscle recruitment ultimately define spinal loading and it is clear that one must understand this activation behaviour.

These early single-equivalent muscle model attempts made it clear that a multiple muscle system representation was needed to describe the activity of the trunk's musculoskeletal system. However, this type of representation further complicated the issue of resolving muscle forces within the torso. Over a dozen muscles can support external forces imposed on the trunk during a MMH task. But only three external forces and three external moments can be monitored outside the body (external forces). Thus, this results in a statically indeterminate situation since there are far more unknowns (internal muscle forces) than knowns (external forces) and it becomes impossible to determine which muscles support the external loads.

Several approaches have been employed to estimate the contribution of the loads in the multiple muscle system. First, assumptions were made about which muscles would be active during a task and which would be silent. This reduced the size of the problem and permitted one to solve for the internal muscle forces and, therefore, estimate spinal loads. Unfortunately, laboratory monitoring of the muscle activities

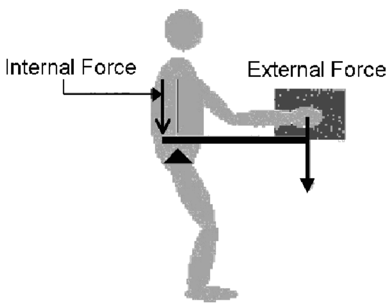


Figure 5. Relationship between internal forces and external forces activity upon the spine.

during simulated MMH rarely indicated that these assumptions were realistic. It was often the case that more muscles were active than assumed.

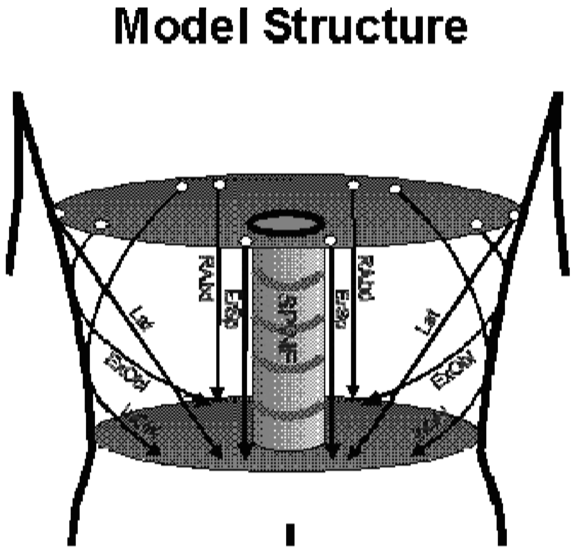
Second, optimization and neural network algorithms assessed the contribution of the internal muscle forces. In the case of optimization, various objective functions have been tested (Schultz *et al.* 1982a, b, Hughes and Chaffin 1995) yet no objective functions could be identified that resulted in a realistic muscle activity descriptions. Optimization often worked under static prolonged loading conditions but failed to predict the coactive nature of the trunk musculature. Neural networks used historical records of muscle activities to predict how muscle would behave during lifting tasks. These networks often classified muscle usage patterns but could not describe the range of responses between workers, nor could they adapt to new lifting situations. In addition, optimization models can not explain the high levels of coactivation often seen in response to motion loading (Granata and Marras 1995) or unexpected loading conditions (Lavender and Marras 1994).

Finally, biologically assisted models estimated the forces generated within the trunk muscle during a lift or MMH activity. Instead of attempting to predict which muscles were active or inactive in response to an external loading condition, biologically assisted models monitor the biological output from many muscles directly to assess which muscles are active in response to an external load. Electromyography (EMG) often monitors the muscles under these circumstances. Models have been developed that interpret the time histories of forces developed in the trunk muscles via the EMG activity and apply these muscle forces to a three-dimensional geometric model of the trunk (figure 6a) (McGill and Norman 1986, Marras and Sommerich 1991a, b, Granata and Marras 1993, 1995). These models are not only capable of predicting the three-dimensional loading of the spine under dynamic lifting conditions, but also can assess the unique spine loading characteristics of an individual worker and monitor how this loading may change (figure 6b). Applications of these models have demonstrated that spine loading varies as a function of repetition (Mirka and Marras 1993, Granata *et al.* 1999), forward bending (Marras and Sommerich 1991b, Granata and Marras 1993, 1995), twisting motion (McGill 1991, Marras and Granata 1995), lateral bending motion (McGill 1992, Marras and Granata 1997) and trunk moment (Marras and Sommerich 1991b, Granata and Marras 1993, 1995). Thus, these models are the most accurate ones available for the assessment of realistic work conditions. Unfortunately, these models require a significant amount of instrumentation and processing time and are not predictive in nature. Thus, each work condition that is to be assessed must be tested.

6.2. *Spine tolerance limits*

As mentioned above, low back pain may also be a result of direct stimulation to the facet joints, pressure on the annulus of the disc or pressure on the longitudinal ligaments. Evaluation of spine loads can also assist in the assessment of how work might be related to experiences of back pain. At these sites, inflammatory responses and analgesic responses typically are involved in the development of pressure and pain. It is much more difficult to specify load tolerance thresholds since the body's individual response to the imposed load collectively define the pressure imposed on the spinal structure. Thus, the tolerance limits for these structures are not well understood at this time.

a



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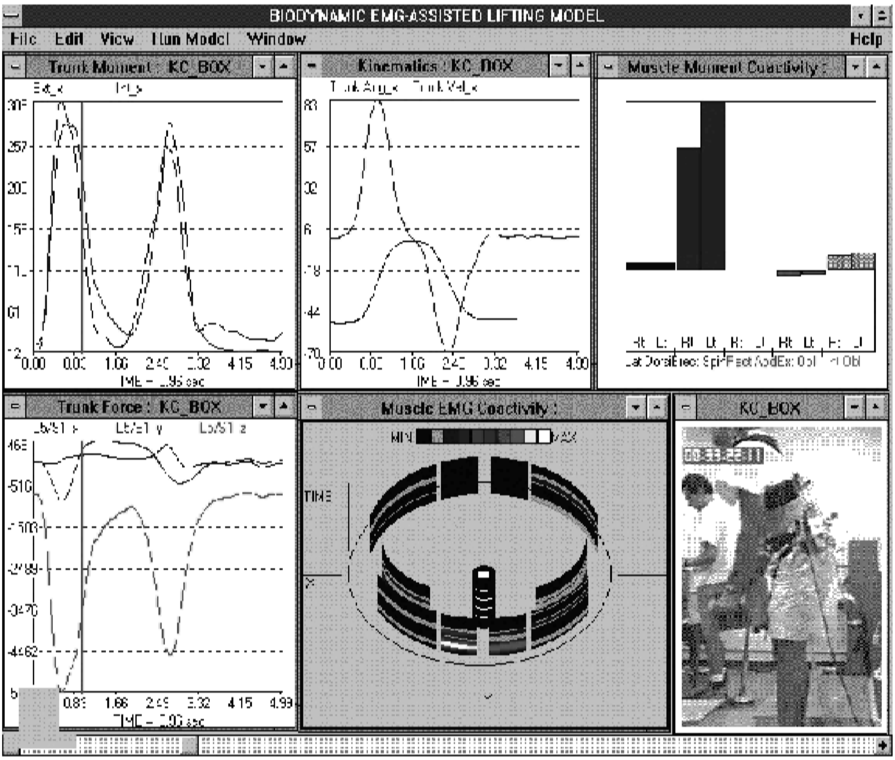

Figure 6. (a) Trunk geometry represented in an EMG-assisted model (Marras and Granata 1997). (b) Example of the EMG-assisted model used in a Windows environment. The environment assists not only in understanding the biomechanical function during a lift, but also allows one to associate the biomechanical behaviour with the video representing the lift of interest.

The magnitude of spine loading must be compared with the tolerance limits of the spine structures to appreciate causality and risk. Owing to ethical considerations, all direct tolerance data have been derived from cadaveric tissue. The obvious downfall of this approach is that *in vitro* tissue is tested that does not have the ability to adapt or recover as does the human at work. Although at least one study suggests that tissue failure might occur at levels even below those observed in cadaveric specimens (Yoganandan 1986). Keeping such potential limitations in mind, estimates of tissue tolerance have been established that serve as benchmarks for risk. Our previous discussion regarding pain pathways has established that the annulus, facet joints and longitudinal ligaments are all capable of becoming the source of chronic low back pain.

6.2.1. *Degeneration process*: Even though one can identify specific areas of the spine that experience pain, to appreciate properly the cumulative trauma process, one must view the spinal structures as a system whose components interact with each other. Figure 7 shows the sequence of events that occurs during work-related degeneration of the spine. This sequence represents one of the major pathways believed to occur for LBD. As indicated in figure 7, excessive loading, generated from both within and outside the body (internal and external forces), cause microfracturing of the vertebral end plates. These end plates serve as a transport system for nutrient delivery to the disc fibres. If this loading becomes excessive and

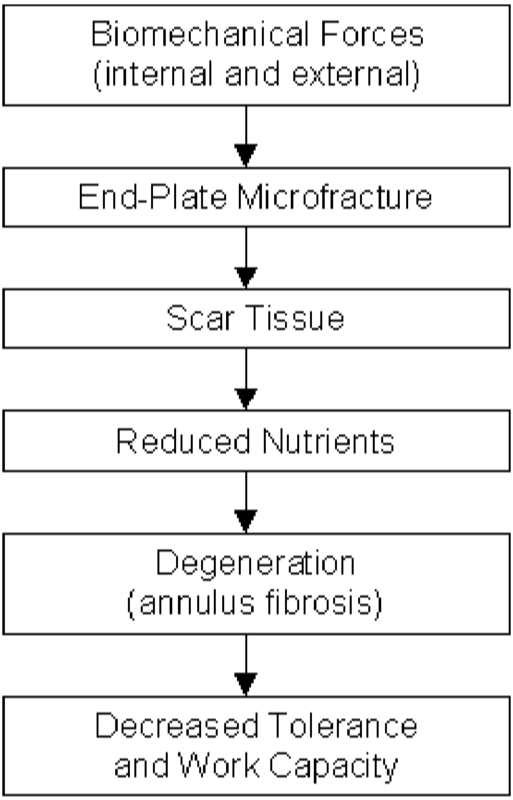

Figure 7. Sequence of events in low back cumulative trauma.

exceeds the end plate tolerance, a microfracture occurs. This microfracture is typically painless since few pain receptors reside within the disc. As healing occurs, scar tissue develops over the microfracture. Since scar tissue is thicker and denser than normal tissue, this scar tissue interferes with nutrient delivery to the disc fibres. This loss of nutrient results in atrophy to the disc fibres and weakens the disc structure. This process represents the beginning of cumulative trauma to the spine and can result in disc protrusions, disc herniation and instability of the spinal system. Recently Lotz *et al*. (1998) demonstrated how disc compression can initiate harmful disc responses that respond according to a dose–response relationship, thus providing further evidence of a cumulative trauma to the spine.

6.2.2. *Vertebrae tolerance*: It has been commonly accepted that compressive loads on the vertebral end plate of 3400 N represent the level at which vertebral end plate micro-fractures begin to occur. Loadings of 6400 N are expected to affect 50% of people under the age of 40 years (NIOSH 1981). Natural variability also dictates the level at which spinal loading becomes problematic. Jager *et al*. (1991) recognized that these limits vary as a function of gender and age. They have developed regression equations that predict the compressive tolerance of the spine as a function of these variables.

Compression tolerance to spinal loading appears to be modulated by additional factors that are significant for workplace assessment purposes. First, Brinkmann *et al*. (1988) performed studies that documented how spine tolerance is reduced as the frequency of loading increases. Compressive strength of the vertebrae is reduced by 30% with 10 loading cycles and by 50% with 5000 loading cycles. This work attempted to address the cumulative trauma or degenerative aspects of work. Second, the relative position or posture of the spine when the load is applied appears to be of great significance to the tolerance of the spine as well as to the ability of the spine to receive nutrients. Adams and Hutton (1982) showed that a fully flexed spine is much weaker than a spine in an upright standing posture (figure 8). Recent studies (Gunning and McGill in press) showed that a flexed spine may be as much as 40% weaker than during an upright posture. Finally, hydration is important and related to the time of day. The spinal system is stiffer and more at risk early in the morning compared with later during the workday (Fathallah *et al*. 1995). Thus, tolerance would be expected to vary throughout the workday.

It has been long recognized that three-dimensional loading of the spine is important for assessing risk, yet tolerances have only recently been estimated for shear loading of the spine. These are expected to occur between 750 and 1000 N (McGill 1997). These tolerances are also expected to be reduced with repetitive loading. It is important to note that these tolerance limits are only a fraction of the tolerance due to compressive loading. Finally, tolerances to combinations of loading have been explored theoretically via finite element models (Shirazi-Adl 1989) but little empirical work is available to support these estimates of tolerance. These studies have helped one to appreciate that tolerances are reduced when loads occur in combination.

6.2.3. *Disc herniation*: Disc herniation from a single application of force is rare. Adams and Hutton (1982) reproduced such failures when the spine was compressed while it was flexed and subject to a complex posture. Furthermore, the risk of

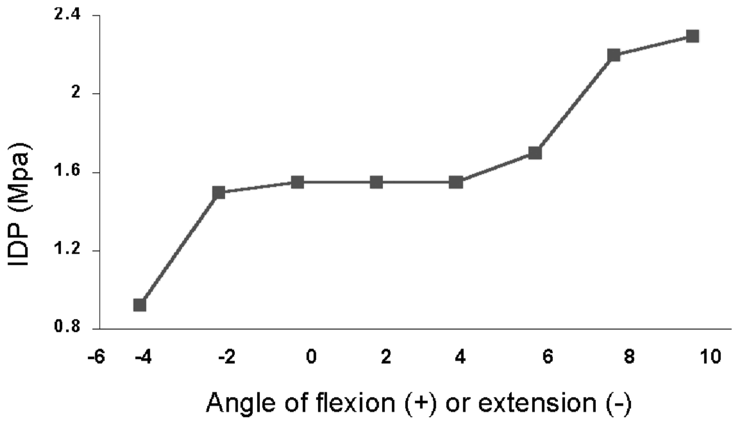

Figure 8. Effect of spine flexion and extension on IDP for a typical specimen (male aged 49, level L_{2-3}). Compressive force= 2000 N (adapted from Adams and Dolan 1995).

herniation increases significantly when the disc is subjected to repeated loading (Gordon *et al.* 1991). This has also been shown to occur for cyclic exposure such as when driving (Wilder *et al.* 1988). Viedman *et al.* (1990) showed that the risk of disc degeneration is not necessarily monotonically related to increases in cumulative loading. They identified a ‘J-curve’ relationship indicating that those exposed to sedentary work are at higher risk of disc injury than those exposed to moderate levels of loading. The risk then increases dramatically when loading increases further beyond the moderate level, thus, describing the ‘J’-shaped relationship.

6.2.4. *Ligaments*: The longitudinal ligament most frequently is subject to excessive tension resulting in avulsion or bony failure as the ligament can tear away bone from its attachment (McGill 1997). Faster motions appear to increase the risk of these avulsions. However, the speed of motion necessary for such tears is much greater than those observed in the workplace unless a sudden slip or fall is responsible for the motion.

6.2.5. *Facets*: The facet joint’s neural arch can withstand shear loads of ~2000 N (Cripton *et al.* 1995) and can also fail in response to torsion loading (Adams and Hutton 1981). The loading of these structures depends greatly upon the posture of the spine throughout the rage of motion. A review by Adams and Dolan (1995) suggests that significant load sharing occurs between the apophyseal joints and the disc. The proportion of the shared load can change dramatically as the spine changes positions.

7. Risk interpretation as a function of the load – tolerance relationship

This review of the load tolerance literature and its relation to the sensation of pain indicates that pain can be associated with physical loading at multiple sites along the spine. It is also apparent that loading and tolerance are both three-dimensional in nature and must be viewed as a system. It is obvious that tolerances to shear and torsion are much lower than those to compression, yet historically assessment techniques have only been concerned with spine compression measures. To make matters more complicated, it appears that the tolerances to injury are modulated by not only load level, but also by repetition, time of day and the posture of the spine when the load is applied. It is obvious from this review that assessing LBD causality and controlling risk is far more complex than simply evaluating one dimension of spine loading at a single point in time. To advance the understanding of causality and control of LBDs, one must begin to develop workplace assessment tools capable of evaluating realistically the three-dimensional loading occurring on the spine dynamically throughout the workday in response to a task. Thus, one must abandon the overly simplistic analysis tools and assess LBD risk at the systems level.

To date only a limited number of studies have evaluated risk as a function of the complex loading occurring at the workplace. Quantitative workplace measures by Marras *et al.* (1993, 1995) and Norman *et al.* (1998) evaluated the kinematic and kinetic factors associated with jobs that put the worker at a high risk of LBD. Both studies have evaluated the three-dimensional factors associated with risk. Their results agree well with the issues most of the load – tolerance model as well as the modulating factors mentioned above.

8. Psychosocial influences on the load – tolerance model

Our earlier review of the epidemiologic literature has shown that some researchers have reported that reactions to the psychosocial environment might explain the relationship between work and LBD. However, if this is true, one must question what link these risk factors might have to LBD development. One might argue that those who are more dissatisfied with their work might be more likely to report work-related low back problems. Thus, it may be possible that psychosocial risk factors may lower the reporting threshold for low back problems. One review of the epidemiologic literature (Ferguson and Marras 1997) clearly shows that there is a sequence of events or time line that occurs in the progression of a LBD report at the workplace (figure 9). Depending on when one chooses to collect data along this time line, one can derive very different results when observing the epidemiologic literature. For example, very different results were observed when reviewing studies that based their conclusions upon reports of discomfort or a report of an incident compared with actual lost time results that required a medical evaluation.

One can argue that if psychosocial risk factors for LBD are truly causal there must be a physiologic pathway to the pain mechanisms discussed earlier. One would expect that such pathways should fit the load – tolerance model if a functional limitation in low back performance can be identified. Recently, Marras *et al.* (2000) explored the presence of such pathways. An experiment was performed that imposed psychosocial stress on people performing standard lifting tasks and compared this with situations where no psychosocial stress was present. Under the stress conditions, significant increases in spine compression and lateral shear were observed, but not for all subjects. Gender played a role in that females moved differently in response to stress, thereby causing an alteration in muscle coactivation patterns. More surprisingly, when the personalities of the subjects was considered, it was found that certain personality traits, such as introversion and intuition, dramatically increased spine loading compared with those with the opposite personality trait (e.g. extroversion and sensing). These differences in personality were closely associated with differing

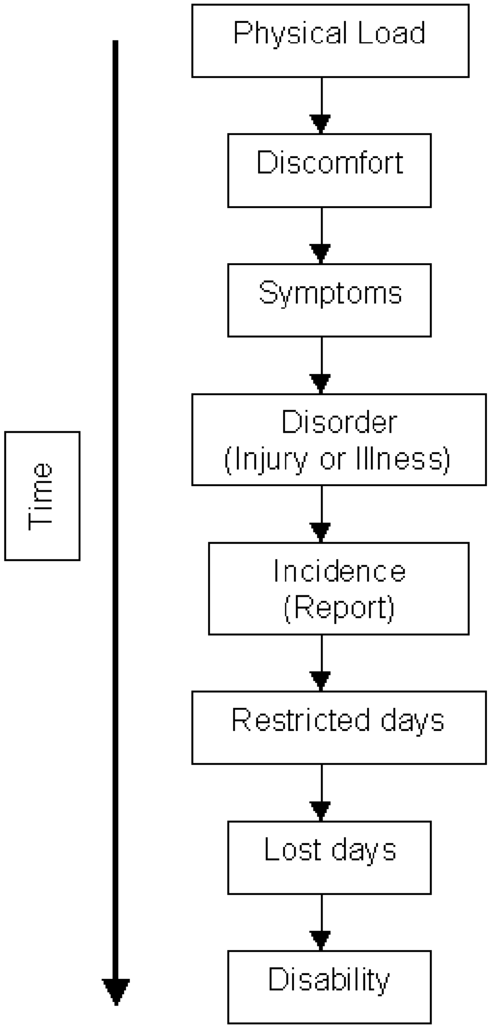

Figure 9. Time progression of low back disorders (adapted from Ferguson and Marras 1997).

trunk muscle coactivation patterns and explained well the difference in spine loading (and expected risk of LBD) between subjects. These increases in trunk muscle coactivation are believed to influence spine loading more at low levels of work intensity than at high levels where the biomechanical demands of the job probably overpower any additional loading that may be due to responses of the musculoskeletal system to psychosocial stress. Thus, this difference in the influence of psychosocial variables on spine loading may be partially responsible for the 'J-shaped' relationship between risk and load described by Videman *et al.* (1990) (figure 10).

This study not only has identified a pathway between psychosocial stress and spine loading, but also has emphasized how examining the interactions of factors suspected of influencing risk can identify the answers to the causality and control of LBD. Thus, collectively these studies suggest the strong interaction of the various components of the human system (biomechanical, physiological, psychological, psychosocial, biochemical) in defining risk. Our research must begin to explore LBD risk at the systems level that includes multiple dimensions of both the physical and mental components of the worker. The National Research Council (1999) has proposed one such interactive model (figure 11).

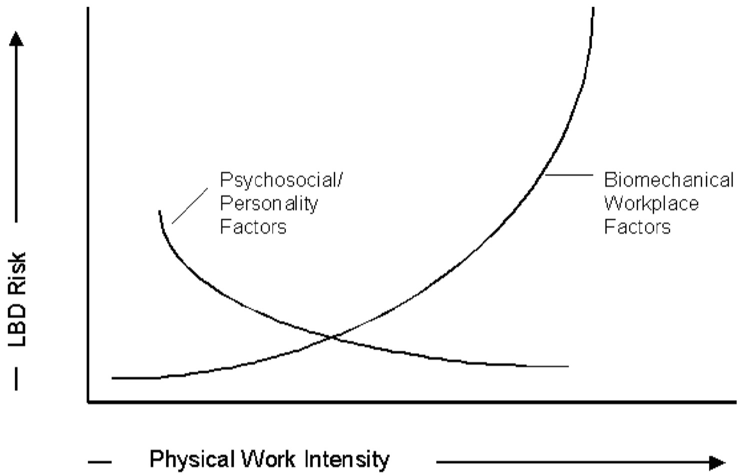

Figure 10. Relationship between workplace biomechanical factors and psychosocial/ personality factors that may account for observed 'J' relationship of risk and work intensity.

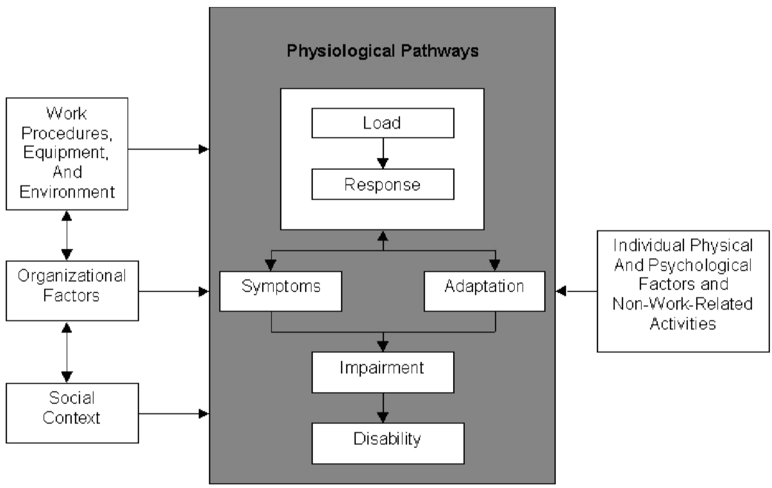

Figure 11. Conceptual framework of physiological pathways and factors that potentially contribute to musculoskeletal disorders (NAS 1999).

9. Interventions

One powerful tool for the assessment of LBD causal and control factors is the intervention study. Only with these efforts can one assess the strength of association between factor and risk under truly realistic circumstances. The most comprehensive literature review to date on ergonomics intervention studies has been by Westgaard and Winkel (1997). This review concluded that all intervention studies were plagued with methodological problems; however, many of these problems are understandable for ethical reasons (e.g. lack of control group when a risk is suspected). Nevertheless, they identified those factors effective in controlling musculoskeletal disorders in the workplace. They concluded that for an intervention to be effective, it must reduce mechanical exposure to the stressor, must actively involve the worker and must affect the organizational culture. No evidence for the effectiveness of interventions such as production system intervention, back schools or relaxation training was observed. Thus, the significance of the mechanical exposures as risk factors further support the load—tolerance model concept. In addition, the significance of organizational support and active worker involvement strongly suggest that cognitive issues associated with the worker may further define how risk occurs in an individual and may help explain the observed variability associated with risk. This further exemplifies the complexity of the risk model and suggests that one needs to understand further LBD risk at a systems level.

10. Future of work

At this point, the nature of work appears to be in transition. It is worthwhile to consider the nature of these trends if one is fully to consider the relationship between work and risk and control of LBD. The most obvious trend in work is that one is moving from a manufacturing society to a distribution society. Manufacturing still occurs and will continue to be a mainstay in many economies. However, the shift in manufacturing is from the more developed countries to the less developed. Much of this is due to changes in world trade policies and the rising costs of labour in some of the more developed countries. Those workers that continue to work in the manufacturing environment are seeing the nature of the work change from one where they work unassisted to one where they use technology to assist them in performing their job. Lift assist devices and intelligent 'cobots' are appearing with increasing frequency in the workplace. These devices change the nature of risk from load support to load management since the devices may make the load virtually weightless but make it more difficult to control the inertial components of the load.

With this shift in manufacturing also developing is an increased need to transport the products. Thus, distribution growth is occurring at a rapid rate. Another factor that is playing a role in the increase in distribution centre growth is the rapid growth of on-line e-commerce or .com businesses. This trend of increases in distribution often requires that products are shipped quicker and place greater speed demands upon the workers in these distribution centres. With these changes, materials handling is shifting from a repetitive task where the same part is handled in the same manner repetitively throughout the work shift to a situation where various items are handled or 'picked' from numerous bins but they are done so rapidly and under time pressures. In addition, the object or package weight is decreasing. Therefore, materials handling is moving from an environment where load weight has traditionally been the risk factor to a situation where variability in repetition and awkward motions performed under time pressures will be expected to be significant risk factors. Clearly, our risk models need to be expanded so they are comprehensive and consider the complex multidimensional nature of LBD risk instead of the simplistic one-dimensional risk assessments that are currently in use.

Another significant trend is a shift to a service economy. Many economies are also moving towards service economies where it might be more difficult to control the physical layout of the work environment since many of these services may be performed in the home or other non-modifiable locations. Such changes, again, have changed the nature of risk to the low back and require a more comprehensive and systematic assessment of LBD risk.

The profile of the worker is also changing. Many workers in manufacturing are older and thus have lower tolerances to load, whereas many of the younger workers now work in the service sector.

11. Conclusions

This review has demonstrated that knowledge of work-related LBD risk factors, and the subsequent potential to control, has progressed over the years, but one still needs to evolve knowledge of the human musculoskeletal torso system further so that one can understand and control risk more effectively. Much of the popular press controversy that clouds the issue of risk assessment and control is based upon political arguments and not the state of the science. The literature clearly shows that knowledge is to the point where one can indeed affect the risk of LBD but it also evident that one can do better.

There are several needs that would help improve our knowledge base relative to LBD risk and control:

- One must begin to understand how variability in the presentation of work affects risk. Variability can be defined in terms of the interaction in variance in: loading, frequency of motion, time pressure, postures and motions, work duration, etc. More specific and quantitative information about these factors is needed for proper evaluation.
- One must begin to understand the influence of non-biomechanical factors such as cognitive processing, personality and psychosocial influences upon the biomechanical load – tolerance model components and the risk of injury.
- One must begin to understand how loads affect tissues *in vivo* and how the biochemical process mediates or exacerbates the cumulative trauma process.
- One needs to realize the limitations of different types of studies and take the results of these studies at their value. No study can be perfect and each type of study has its own limitations. Thus, epidemiologic studies must be viewed in the context, as should biomechanical, physiological, biochemical, psychophysical, and psychosocial studies. The true picture of risk is only evident when quality studies are viewed systematically and collectively, regardless of the nature of the methodology used.
- One must adapt a systems approach to evaluating LBD in the workplace. Our models must begin to asses risk as a biomechanical – physiologic – cognitive – perception – tissue sensitive – biochemical system.
- There is a dire need for high quality intervention studies.

Collectively, advances in these areas will allow us to improve our knowledge of LBD risk and control and will facilitate the mediation of human suffering at the workplace.

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