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National occupational research agenda (NORA) future directions in occupational musculoskeletal disorder health research ☆

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Abstract

Musculoskeletal disorders are among the most costly health care problems facing society today. The scientific literature has indicated that psychosocial factors, individual factors, workplace physical requirements, and workplace organizational factors have been associated with risk. Since musculoskeletal risk is multi-dimensional, the magnitude of risk attributable to various factors can be of importance to scientists and policy makers in designing countermeasures to reduce injury incidence. Traditionally, the disciplines of biomechanics, physiology, and psychophysics have dominated the body of knowledge that has defined exposure limitations to work. However, recent research has explored the association of psychosocial and work organization factors with musculoskeletal problems. Advances have been made to better quantify the levels of occupational exposure by improved exposure metrics, quantification of three-dimensional loads experienced by certain joints (e.g. the spine), identification of tissue tolerance limits and tissue response to mechanical stresses, and the impact of psychosocial stresses. However, efforts to quantitatively link epidemiological, biomechanical loading, soft tissue tolerance, and psychosocial studies should be pursued to establish a better understanding of the pathways of injury and resultant preventive strategies. Although we are beginning to understand how the major risk factors influence the load–tolerance relationship of human tissue, how these risk factors interact is virtually unexplored. Since the impact of the interactions may be far greater than that of any individual factor, the impact of the interactions between risk factors must be delineated so that work-related risk can be better quantified. Efforts to quantitatively link epidemiological, biomechanical loading, soft tissue tolerance, and psychosocial studies should be pursued to establish a better understanding of the pathways of injury and resultant preventive strategies.
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Contents

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1. National perspective

The National Institute for Occupational Safety and Health (NIOSH) recognizes that addressing the high incidence rate of work-related musculoskeletal disorders (MSDs) requires coordination and cooperation among its many external partners. This philosophy underpins NIOSH's National Occupational Research Agenda (NORA), a collaborative effort between NIOSH and its partners to guide occupational safety and health research into the 21st century. In the first decade of NORA, which began in 1996, 20 teams were formed to develop research agendas. One of these teams was the NIOSH NORA MSD team, a team comprised of experts representing a broad range of industry, labor, and government interests who were assembled to evaluate the status and define future research needs in the area of work-related MSDs. The team published a comprehensive research agenda in 2001 (NIOSH, 2001). It was anticipated that this research agenda would serve as a blueprint for building a national research program by identifying high priority research problems and influencing the allocation of resources. In 2006, NIOSH modified the organizational structure of the NORA teams and placed a special emphasis on eight primary industry sectors that included Agriculture, Forestry & Fishing, Construction; Healthcare & Social Assistance; Manufacturing; Services; Transportation, Warehousing & Utilities; and, Wholesale and Retail Trades, with addition of a number of cross-sector teams and special emphasis teams, which includes musculoskeletal disorders. Most of the NORA industry sector teams have established preliminary strategic goals aimed at reducing the incidence and severity of work-related musculoskeletal disorders (MSDs) in the workplace. For information on the new NORA structure, visit the NIOSH NORA web site (http://www.cdc.gov/niosh/NORA/).

Since the publication of the 2001 research agenda, members of the NORA MSD team further evaluated the list of research gaps originally identified in the research agenda report and identified areas of research that were considered to be of a high priority. The evaluation suggested that identifying risk factors associated with MSDs, understanding how various exposures result in non-traumatic soft tissue injuries, and identifying mechanisms for reducing the incidence and severity of these disorders should be of paramount importance to NIOSH. The findings from this effort are detailed below.

2. Recent studies for identification of risk factors

Review of the literature and economic data by the NORA MSD team indicated that musculoskeletal disorders (MSD) related to the workplace are among the most costly health problems facing society today (N.R.C., 1999, 2001a). Currently, the low back and the upper extremities are the parts of the body most subject to risk associated with work (Andersson, 1997; Bongers, 2001; Dennerlein et al., 1999; Ferguson and Marras, 1997; Katz et al., 2000; Marras et al., 2000a, 2001; Oleske et al., 2000; Rempel et al., 1992, 1998; Viikari-Juntura and Silverstein, 1999; Roquelaure et al., 2006). There is consensus that non-specific upper-limb symptoms and specific upper-limb MSDs are common in the working population (Roquelaure et al., 2006) as well as low back symptoms (Morken et al., 2003). The literature recognizes that MSD risk arises from several simultaneously contributing factors. A number of conceptual models have been proposed to address the etiological mechanisms linking exposure to the risk factors for work-related MSDs and the development of health outcomes. One such model included in the NORA Research Agenda for MSDs is shown in Fig. 1 (NIOSH, 2001). This model is similar to the model proposed by the National Academy of Sciences (N.R.C., 2001a). Individual factors, workplace physical requirements, organizational factors, and psychosocial factors have been associated with risk (Bigos et al., 1991; Burdorf and Sorock, 1997; Dasinger et al., 2000; Deyo and Bass, 1989; Hoogendoorn et al., 2000a, b; Norman et al., 1998; Huang et al., 2002). It is known that the contribution of each factor to the risk of a workplace musculoskeletal injury varies with the nature of the disorder and the anatomical area involved (Rempel et al., 1992). Reviews of epidemiological studies indicate that between 11% and 80% of low-back injuries and 11–95% of extremity injuries, are attributable to workplace physical factors, whereas, between 14% and 63% of injuries to the low back and between 28% and 84% of injuries of the upper extremity are attributable to psychosocial factors (N.R.C., 2001a, b; Huang et al., 2002). Since risk is multidimensional, the fractions attributable to various factors can help scientist and policy makers determine the extent to which a musculoskeletal disorder would be reduced if a particular risk factor were reduced or controlled. The goal of ergonomic science is to understand the causality of work-related musculoskeletal disorders and to apply this knowledge to reduce work-related risk. Traditionally, the disciplines of biomechanics,

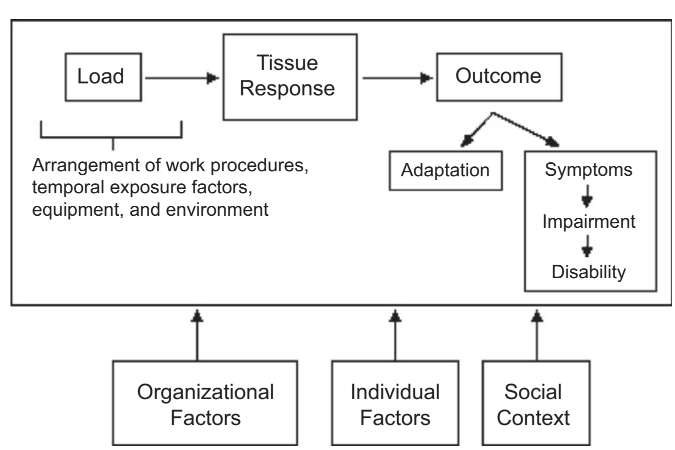

Fig. 1. Conceptual model for the development of musculoskeletal disorders (NIOSH, 2001).

physiology, and psychophysics have dominated the body of knowledge that has defined exposure limitations to work. More recently, research has explored the association of psychosocial and work organization factors (e.g., job satisfaction, supervisor support, safety climate, work stress) with both lower extremity and upper extremity musculoskeletal disorders (Hoogendoorn et al., 2000b; Marras et al., 2000b; Waters et al., 2007; Lee et al., 2005; Devereaux et al., 2004; Bongers et al., 2002; N.R.C., 2001a; Gell et al., 2005). For example, NIOSH's recent creation of a Quality of Worklife Module, which collects data on lower and upper extremity MSDs and psychosocial and work organization factors, as part of the General Social Survey, will add to the overall knowledge base of risk factors for MSDs. Thus, a better understanding of the mechanisms leading to these disorders through ongoing research will facilitate better prevention strategies to ultimately reduce the incidence of musculoskeletal disorders in the workplace.

3. Recent advances

Over the past decade, several significant advances have improved our understanding of MSD causality. First, improved exposure metrics have made it possible to more accurately quantify the physical characteristics of the environment to which workers are exposed and to specify the levels of exposure that significantly increase workplace musculoskeletal risk (Deyo et al., 1998; Fathallah et al., 1998; Ferguson and Marras, 1997; Granata and Marras, 1995; Lavender et al., 1989, 1999a, b; Marras et al., 1993; McGill, 1997). Objectively measuring the nature of the physical load involved in a given work task, the degree of the repetition required to performing a certain task, as well as the kinematics (movements) and time needed to accomplish a specific task have improved our ability to define ''overexposure'' for a given work condition (Lavender et al., 1999a; Marras et al., 2001; Marras and Granata, 1997a; Marras et al., 1993; Solomonow et al., 1999).

Second, the ability to understand the three-dimensional loads experienced by certain joints (e.g. the spine) during work-related exertions (e.g. lifting tasks) has improved significantly with the development of biologically assisted engineering mechanical models and static and dynamic stability models of the spine (Marras et al., 1999; Cholewicki et al., 2000; Granata and Wilson, 2001; McGill, 2001; McGill and Cholewicki, 2001; McGill and Kippers, 1994; Solomonow et al., 1998; Stokes and Frymoyer, 1987; Wilke et al., 1995; Marras and Granata, 1997b).

Third, our understanding of tolerance limits to biomechanical load has improved significantly through the use of *in vitro* and *in vivo* animal models and finite element modeling techniques (Callaghan and McGill, 2001; Lotz and Chin, 2000; Natarajan et al., 1994; Panjabi et al., 1985; Rempel and Abrahamsson, 2001; Shirazi-Adl, 1991; Videman et al., 1990; Cutlip et al., 2004, 2005, 2006; Barr and Barbe, 2004; Barbe and Barr, 2006; Barbe et al., 2003; Baker et al., 2006a ,b, 2007; Geronilla et al., 2003). We have begun to understand the tissue deterioration process due to occupational loading (Adams, 1988; Adams et al., 2000; Callaghan and McGill, 2001; Hutton et al., 2000; Lotz and Chin, 2000; Natarajan et al., 1994; Viikari-Juntura and Silverstein, 1999; Barr and Barbe, 2004). With such techniques, the ability to specify tolerance limits for the spine has improved significantly. While early studies permitted an assessment only of the static upright positions of the spine, later efforts have defined tolerance limits in response to dynamic conditions of bending, repetition, and asymmetry (Adams, 1988; Granata and Marras, 1995; Hoogendoorn et al., 2000a; Kirkaldy-Willis, 1998; Lavender et al., 1989; Marras and Granata, 1997a, c; Thelen et al., 1995).

Fourth, understanding of tissue response to loading has recently begun to consider the role of pro-inflammatory responses by particular peripheral nerves which may release cytokines and neurotransmitters (substance P, Bradykinin, Tumor Necrosis Factor-alpha, Prostaglandin E_2, etc.) that stimulates the sensation of pain (Cavanaugh, 1995; Cavanaugh et al., 1997; Rempel et al., 1999; Siddall and Cousins, 1997). Inflammatory cytokines can increase Prostaglandin E_2 synthesis which acts at both peripheral free nerve endings of sensory neurons and at central sites within the spinal cord and brain to increase pain sensation (Peters et al., 1990). Post-injury pain can also be mediated by central sensitization via the up-regulation of nerve growth factor (NGF) that may increase the excitability of spinal neurons after peripheral musculoskeletal injury (Topper et al., 1997). Although, the entire pathway leading to chronic pain is unclear, it is important to understand the relation between mechanical exposures, soft tissue response, and pain (Mense, 2001).

Fifth, pathomechanics investigates the physiological response of musculoskeletal tissue to single and multiple mechanical exposures (Cutlip, 2006). This field of inquiry will help elucidate the factors that produce acute (Hunter and Faulkner, 1997; Cutlip et al., 2004, 2005; Baker et al., 2007; Faulkner et al., 1989; Geronilla et al., 2003) and chronic (Cutlip et al., 2006; Barbe et al., 2003) soft tissue injury, characterize the resultant physiological response due to injurious mechanical exposure (Geronilla et al., 2003; Baker et al., 2006a, b, 2007; Krajnak et al., 2006), and describe the reparative mechanisms that result after tissue injury (Lapointe et al., 2002a, b; Peterson et al., 2003; Rabinovsky et al., 2003; Sheehan and Allen, 1999; Trappe et al., 2001, 2002). Improvements in pathomechanics have allowed better understanding of the response of tissues to repeated mechanical exposures (Cutlip et al., 2006). Recent studies have shown how repetitive loading results in chronic injury to muscle and tendon tissues (Cutlip, 2006). The histological and biochemical responses to different exposures are being defined, and the interaction between biomechanical loading, tissue response, and pathways responsible for maladaptive or adaptive responses are being explored. These findings have relevance to both low back and upper extremity workplace injuries.

Sixth, the role of psychosocial factors has been better delineated (Andersen et al., 2002; Warren, 2001). Psychosocial factors include non-physical influences that concern the mental stress response of the worker in the workplace. The risk factors associated with psychosocial factors associated with workplace organizational structures and social contexts that make up a workplace environment have been defined (Bigos et al., 1991; Karjalainen et al., 2001; Waddell, 1992).

Finally, the pathways by which multi-dimensional factors might influence spine loading have been initially described. The role of personality factors and psychosocial factors in influencing muscle coactivity and subsequent spine loading has been described (Marras et al., 2000b). These pathways also are relevant to upper limb disorders as well (Vasseljen et al., 2001).

4. Future research directions

Traditionally, high force, highly repetitive loading of the musculoskeletal system has been the hallmark of work. However, the workplace and the nature of the work are changing rapidly. Manufacturing, where employees work on a traditional assembly line is decreasing. However, those that remain employed in these environments are increasingly exposed to more frequent but less forceful motions (Punnett et al., 1991, 2000). More assembly is occurring in work cells where employees perform a variety of tasks and may rotate through different work stations throughout the day. The service sector of society is increasing rapidly. This work can involve tasks in a variety of non-conventional environments. With the introduction of e-commerce, a vast increase in distribution center jobs has also occurred where order picking is becoming a common task for many workers. Collectively, these trends indicate that the nature of physical exposure is rapidly evolving to a low-force, highly repetitive environment where the repetition may involve different vectors of force application. Research efforts must now examine these new environments with protocols adapted to this new form of musculoskeletal loading (Westgaard and Winkel, 1997).

Given recent advances in research and the changing work environment, several paths for future research emphasis are clear. Research efforts must be directed towards better quantifying the role of the various risk factors in the mix of exposures common in the workplace. Efforts to quantitatively link epidemiological, biomechanical loading, soft tissue tolerance, and psychosocial factors studies should be pursued to establish a better understanding of the pathways of injury and resultant preventive strategies. Quantification of physical risk factors, rather than reliance on self-reported measures would strengthen our knowledge of the relationship between exposure and development of work-related MSDs (Waters et al., 2007). Although we are beginning to understand how the major risk factors influence the load-tolerance relationship of human tissue, how these risk factors interact is virtually unexplored. Since the impact of the interactions may be far greater than that of any individual factor, the impact of the interactions between risk factors must be delineated. For example, much of the literature implies that psychosocial factors influence risk at low levels of force, whereas biomechanical factors override psychosocial influences at higher levels of force. The contributions of these various categories of influence must be better delineated so that work-related risk can be better quantified.

Further work is needed to clarify the response of tissue to loading and the pain pathways associated with this relationship. Much of our knowledge about tissue tolerance, especially that related to repetitive loading, has been gained from cadaver studies. Such data do not reflect the biological system's ability to temporally adapt to conditions that occur during actual working conditions. Future research efforts should examine the *in-vivo* tolerance of healthy as well as compromised populations.

A worldwide trend in the surveillance data indicates that shoulder problems are common and are occurring with increased frequency in the workplace. This trend appears to be unrecognized in US injury statistics. Better surveillance is needed to appreciate the magnitude of risk associated with shoulder loading in the workplace (Katz et al., 2000; Punnett et al., 2000; Vasseljen et al., 2001). In addition, a void exists in our ability to accurately predict loading of the shoulder due to work tasks (Dickerson et al., 2007). As well, our understanding of tissue tolerance to such 3-D loads imposed on the shoulder is extremely poor. All of these areas represent vital research opportunities. As people live longer, and the average age of the U.S. work force increases, the impact of aging on work-related loading, tolerance, psychosocial stress, and their interactions must be better investigated.

The role of workplace factors in the development of myalgia has been virtually unexplored; yet many symptoms of work-related musculoskeletal disorders resemble myofascial pain (Bathaii and Tabaddor, 2006; Hayden et al., 2006; Eriksen, 2004). Research efforts must focus on how low-level sustained or repetitive exertions, prevalent in the workplace, may influence muscle recruitment patterns, result in soft tissue disruption, and pain and dysfunction (Sjogaard and Sogaard, 1998; Sjogaard et al., 2000; Sjogaard and Jensen, 1997).

Research involving the risk of secondary injury associated with return-to-work is sparse (Frank et al., 1996a; Wasiak et al., 2007). Studies that integrate epidemiological data, biomechanical exposures, soft tissue pathomechanics, and psychosocial data are needed to determine and describe how the risk of injury is amplified when an individual is exposed to work while recovering from a musculoskeletal disorder (Wasiak et al., 2007).

A continuing need exists for high-quality intervention studies (Frank et al., 1996b; Anema et al., 2007). Problems associated with these experimental controlled studies are a function of the pragmatic aspects of performing intervention studies in a dynamic industrial environment. Alternative research designs are needed to decisively assess the impact of these interventions on the risk of workplace musculoskeletal injury. Most research has focused on the causal relationship between work and musculoskeletal disorders. The effectiveness of intervening in this relationship can also be established standardizing research metrics and designs throughout several intervention studies. This could help to develop alternative control technologies that help to develop high quality intervention research. Studies must overcome the traditional limitations in these efforts to better establish causality and effectiveness of interventions.

In summary, understanding the current body of MSD research and the identification of research gaps is necessary for development of more robust and realistic models of occupational MSDs. This effort as a research community will aid in better workplace design, exposure parameters, diagnosis of injury, return to work assessment, and ultimately lower risk, reduced medical costs, and healthier workers.

Disclaimer

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