International Journal of Industrial Ergonomics 43 (2013) 356–362

Contents lists available at SciVerse ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

External load and the reaction of the musculoskeletal system – A conceptual model of the interaction

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ARTICLE INFO

Article history:
Received 24 May 2012
Received in revised form
14 March 2013
Accepted 8 April 2013
Available online 23 July 2013

Keywords:
Musculoskeletal disorders
Musculoskeletal load
Psychosocial factors
Exposure
Dose-response

ABSTRACT

This paper presents a conceptual model of the interaction between the human body and external factors influencing the musculoskeletal system (biomechanical load, vibration and psychosocial factors). The interrelationship of parameters that define each external occupational or non-occupational factor and their combination creates exposure. Exposure influences the human body modelled as a mental system and a musculoskeletal system, and results in responses leading to improved or impaired structures of the musculoskeletal system. The reaction to external factors expressed as a response depends on personal traits. The results of this study are a basis for insights into how external physical and psychosocial risk factors influence the mechanisms responsible for whether body structures improve or are impaired. The model is intended to be filled in with mathematical equations that describe quantitatively phenomena related to processes caused by external load, with consideration of personal traits. This paper discusses ways leading to mathematical formulas, which would explain the phenomena included in the model quantitatively.

Relevance to industry: The relevance of this study to industry consists in providing, through the use of the proposed model, after a quantitative verification, safety levels that can result in improved work and workers protect against MSDs. By considering both occupational and non-occupational activities, the model can help to protect workers holistically.

1. Introduction

Disorders of muscle tissues and their surrounding structures, i.e., musculoskeletal disorders (MSDs), indicate health problems of the locomotor apparatus. MSDs are impairments of body structures, such as muscles and tendons, joints, cartilage, ligaments, nerves, the skeleton and blood vessels. They mostly result from the cumulative effect of long-lasting load of various magnitude. A wide range of external factors in the work environment cause MSDs. In addition to work, aspects of the daily life can contribute, too. Therefore, MSDs depend on both occupational and non-occupational factors (Habib et al., 2011).

Numerous epidemiological studies, which sought to identify external factors positively or negatively associated with the development of MSDs in various body parts, proved that biomechanical load (Punnett et al., 2005), vibration (Bovenzi, 2008) and psychosocial factors (Smith et al., 2006; Huang and Feuerstein, 2004) were important.

Heavy physical work, e.g., lifting and carrying, pushing, pulling and manipulating heavy load, is a classic task leading to the development of MSDs (Hoogendoorn et al., 2002; van Niewenhuyse et al., 2006). Very specific tasks, like handling patients (Smith et al., 2006), were found to pose risk for the low back too. However, office work (Choobineh et al., 2011) or work at an assembly line, packing small objects, etc., i.e., work which mostly involves upper limbs in repetitive tasks with static load of the back also causes musculoskeletal disorders (Bosch et al., 2007). Systematic reviews confirmed repetitive and forceful movements of the upper limbs as risk factors for the development of MSDs (van den Windt et al.'s, 2000).

Those studies linked physical effort associated with postures, exerted forces and time sequences to the development of MSDs. On the other hand, physical effort during training programs with heavy load resulted in outcomes beneficial for the human body. Rooks et al. (2002) showed that a program of strength training effectively improved muscle strength and cardiovascular endurance. Strength and endurance training as well as stretching and fitness training were effective in decreasing pain and disability in women

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http://dx.doi.org/10.1016/j.ergon.2013.04.002

with chronic, nonspecific neck pain (Ylinen et al., 2003). Similarly, coordination and endurance training for patients with chronic low back pain proved to be effective treatment (Johannsen et al., 1995). Vouri (1998) justified physical activity and summarized its effect on physiological responses. He emphasized positive effect of moderate daily physical activity. Thus, physical load induced by biomechanical measures related to posture and exerted forces can result not only in impaired body structures leading to MSDs but to improved health as well.

The impact of vibration is also dichotomous. Numerous studies on the negative impact of vibration on muscles have focused on the effect of whole body vibration (WBV). It is well-documented that exposure to WBV is a risk factor for low back pain (Burdorf and Sorock, 1997; Tiemessen et al., 2008; Lis et al., 2007). Similarly, Heaver et al. (2011) and Astrom et al. (2006) showed hand-arm vibration (HAV) to be a major risk factor for the development of MSDs in workers who use grinders, drills, saws, hammers and other vibration tools. Regular and frequent exposure to HAV leads to the HAV syndrome (HAVS) (Youakim, 2010; Bovenzi, 2008; Mahbub and Harada, 2011).

On the other hand, vibration can be a beneficial factor, e.g., for patients with spinal cord injury (Murillo et al., 2011). Exposure to vibration can improve the rehabilitative effect (Jackson et al., 2008; Ahlborg et al., 2006). Vibration can be effective in improving balance (Wunderer et al., 2008; Mani et al., 2010) and bone mineral density (Rehn and Nilsson, 2008). It is also used in sport applications (Cardinale and Bosco, 2003). Supporting exercise with vibration has been shown to be effective not only in improving muscle strength (Roelants et al., 2004; Rehn et al., 2007) and muscle power (Cochrane and Stannard, 2005) but also the ability to jump (Cochrane et al., 2004).

Workload was proved to depend on the type of task and to stem not only from physical factors but also from psychosocial ones. There is a growing awareness of the link between occupational psychosocial factors and MSDs (Bongers and Kremer, 2002; van der Windt et al., 2000). Studies seem to confirm the hypothesis that a poor psychosocial situation results in higher reports of symptoms in the wrist/hand, shoulders (Bongers and Kremer, 2002; Eatough et al., 2012; Wahlstedt et al., 2010) and low back (Eatough et al., 2012). However, psychosocial factors may or may not be associated with impairment of human body structures. According to Karasek's model (Karasek et al., 1998), psychological demands of work combined with control are a combination of factors that are either harmful or beneficial, i.e., produce either negative or positive stress. A combination of those factors creates a level of demands necessary for effective performance to take place as opposed to a level at which a combination of factors produces excessive mental load and the effect of this exposure is harmful. Chiang et al. (2010) showed that job demands might not be stressful, particularly if a person has control over responsibilities and receives sufficient support. That proves that psychosocial external factors, too, can both harm and improve health.

Interactions between factors are also important. Vibration in conjunction with biomechanical load caused by awkward postures, excessive force and repetitive movements, was proved to be the cause of the development of disorders like carpal tunnel syndrome (Bovenzi et al., 2000). Awkward postures with additional whole-body vibration (WBV) increase the risk of low back pain even four times compared with the sitting posture only (Lis et al., 2007). Combined exposure to physical and psychosocial workload also increases risk of musculoskeletal injuries (Koehoorn et al., 2006; Devereux et al., 2002). External factors interact not only among themselves but also with the personal traits of an individual (Huang et al., 2002; Kumar and Kumar, 2008), which also contribute to the development of MSDs (Burdorf and Sorock, 1997). Thus, predicting the influence of external factors at the level of an individual is difficult. Negative outcomes of psychosocial factors may be decreased by resources related to physical, psychological, social or organizational aspects (Schaufeli and Bakker, 2004).

Understanding and establishing mechanisms leading to impairment or improvement of health condition is elusive. However, it is not only the interaction between factors that makes precise conceptualizing of the causation between factors and outcomes. Proper criteria would discriminate positive and negative influence. Thus, (a) a conceptual model of exposure and outcomes, (b) a quantitative relationship between factors and outcomes and (c) criteria are expected. Thus, there is a need for theories on the mechanisms of impairment or improvement of the condition of body structures as a reaction to external factors and personal traits. Such a concept of a relationship between external factors and personal traits could be a basis for developing a precise quantitative relationship between exposure and outcomes resulting in impairment or improvement of body structures condition.

Huang et al. (2002) reviewed literature on concepts and models of psychosocial and individual factors and their interaction, and their influence on the development of work-related MSDs. Existing concepts target occupational factors while accepting, to a limited extent, non-occupational load (Huang et al., 2002). They present an interaction of external factors leading to the development of MSDs; however, they neither consider nor discuss the beneficial effects of the same factors, which depend on variations in the exposure or time of exposure.

This paper aims to present a concept of an interaction between exposure and outcomes, which would be a basis for quantitative modeling of the relationship between external and internal factors and outcomes of harmful or beneficial effects to the human musculoskeletal system.

The concept presented here builds on an earlier approach to the interrelationship between external factors and personal traits, mostly Armstrong's et al. (1993). It leads in the direction of a quantitative, based on mathematical formulas, expression of the relationship between external factors, internal processes and outcomes. However, it does not present such. It does not discriminate if an external factor is occupational or non-occupational. The concept behind this model considers the interaction between the human body and the external factors. Even though this model combines external and internal factors, it focuses on the former, which impose load; however, in the context of internal phenomena.

2. The model

2.1. External factors – exposure

Biomechanical load, vibration and psychosocial factors influence development of MSDs. Therefore, the concept behind the model considers both impairment and improvement of the condition of body structures. The model embraces those positive and negative changes as associated with biomechanical load (B), vibration (V) and psychosocial factors (S). The interrelationship of parameters that define individual external factors and their combination creates exposure (E).

Biomechanical load (B) is a result of various physical activities characterized with biomechanical parameters, which define posture, force and time. The most reliable way to describe body posture is with angles in joints in three planes: sagittal, frontal and transverse. Force is described with the type of force activity (pushing, pulling, squeezing, etc.) and its values. Time describes how long a given posture and exerted force are sustained; it can also characterize the repetitiveness of tasks with respect to more and less forceful movements.