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Work-Related Musculoskeletal Disorders Assessment and Prevention

Isabel L. Nunes¹ and Pamela McCauley Bush²

¹*Centre of Technologies and Systems,
Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa,*

²*University of Central Florida,*

¹*Portugal*

²*USA*

1. Introduction

Work-related musculoskeletal disorders (WMSD) related with repetitive and demanding working conditions continue to represent one of the biggest problems in industrialized countries.

The World Health Organization (WHO), recognizing the impact of 'work-related' musculoskeletal diseases, has characterized WMSD s as multifactorial, indicating that a number of risk factors contribute to and exacerbate these maladies (Sauter et al., 1993). The presence of these risk factors produced increases in the occurrence of these injuries, thus making WMSD s an international health concern. These types of injuries of the soft tissues are referred to by many names, including WMSD s, repetitive strain injuries (RSI), repetitive motion injuries (RMI), and cumulative trauma disorders (CTDs) (McCauley Bush, 2011).

WMSD are diseases related and/or aggravated by work that can affect the upper limb extremities, the lower back area, and the lower limbs. WMSD can be defined by impairments of bodily structures such as muscles, joints, tendons, ligaments, nerves, bones and the localized blood circulation system, caused or aggravated primarily by work itself or by the work environment (Nunes, 2009a).

Besides the physically demanding of the jobs the ageing of the workforce are also a contribution to the widespread of WMSD , since the propensity for developing a WMSD is related more to the difference between the demands of work and the worker's physical work capacity that decreases with age (Okunribido & Wynn 2010).

Despite the variety of efforts to control WMSD, including engineering design changes, organizational modifications or working training programs, these set of disorders account for a huge amount of human suffering due to worker impairment, often leading to permanent, partial or total disability.

WMSD have also heavy economic costs to companies and to healthcare systems. The costs are due to loss of productivity, training of new workers and compensation costs. These costs are felt globally, particularly as organizations begin to develop international partnerships for manufacturing and service roles.

Conclusions derived from the 4th European Working Conditions Survey (conducted in 2005 in 31 countries: EU27 plus Norway, Croatia, Turkey and Switzerland by European Foundation for the Improvement of Living and Working Conditions) state that about 60 million workers reportedly suffer from WMSD in Europe. Therefore, within the EU, backache seems to be the most prevalent work-related health problem, followed by overall fatigue (22.5%) and stress (22.3%). Variability among Member States' self reported backache levels are high, ranging from a maximum of 47%, in Greece, to a minimum of 10.8%, in the United Kingdom. Self-reported WMSD from the newer Member States tend to be higher: overall fatigue (40.7%) and backache (38.9%) (EUROFOUND, 2007).

The same European Foundation according to data from the 5th European Working Conditions Survey, which have collected data during 2010 from around 44,000 workers in 34 European countries (EU27, Norway, Croatia, the former Yugoslav Republic of Macedonia, Turkey, Albania, Montenegro and Kosovo) concluded that European workers remain exposed to physical hazards, which means that many Europeans' jobs still involve physical labour. For instance, 33% of workers carry heavy loads at least a quarter of their working time, while 23% are exposed to vibrations. About half of all workers (46%) work in tiring or painful positions at least a quarter of the time. Also repetitive hand or arm movements are performed by more Europeans than 10 years ago. Women and men are exposed to different physical hazards, due to gender segregation that occurs in many sectors (EUROFOUND, 2010). This report reveals also that, 33% of men, but only 10% of women, are regularly exposed to vibrations, while 42% of men, but 24% of women, carry heavy loads. In contrast, 13% of women, but only 5% of men, lift or move people as part of their work. However, similar proportions of men and women work in tiring positions (48% and 45% respectively), or make repetitive hand and arm movements (64% and 63% respectively).

WMSD are the most common occupational illness in the European Union; however, it would appear that musculoskeletal disorders directly linked to strenuous working conditions are on the decline, while those related to stress and work overload are increasing (EUROFOUND, 2010). Pain in the lower limbs may be as important as pain in the upper limbs, but there is limited research to support pain as a symptom, associated risk factors and broad evidence that has been recognized as specific lower extremity WMSD risk factors (EU-OSHA, 2010).

2. Work related musculoskeletal disorders

The recognition that the work may adversely affect health is not new. Musculoskeletal disorders have been diagnosed for many years in the medical field. In the eighteenth century the Italian physician Bernardino Ramazzini, was the first to recognize the relationship between work and certain disorders of the musculoskeletal system due to the performance of sudden and irregular movements and the adoption of awkward postures (Putz-Anderson, 1988). In old medical records is also possible to find references to a variety of injuries related to the execution of certain work. In the nineteenth century, Raynauld's phenomenon, also called dead finger or jackhammer disease, was found to be caused by a lack of blood supply and related to repetitive motions. In 1893, Gray gave explanations of inflammations of the extensor tendons of the thumb in their sheaths after performing extreme exercises. Long before the Workers' Compensation Act was passed in Great Britain (1906) and CTDs were recognized by the medical community as an insurable diagnosis,

workers were victims of the trade they pursued. Since these injuries only manifest themselves after a long period of time, they often went unrecognized (McCauley Bush, 2011).

Some disorders were identified by names related with the professions where they mainly occurred, for instance 'carpenter's elbow', 'seamstress', 'wrist' or 'bricklayer's shoulder', 'washer woman's sprain,' 'gamekeeper's thumb,' 'drummer's palsy,' 'pipe fitter's thumb,' 'reedmaker's elbow,' 'pizza cutter's palsy,' and 'flute player's hand' (Putz-Anderson, 1988) (Mandel, 2003). During and after the 1960s, physiological and biomechanical strains of human tissue, particularly of the tendons and their sheaths, revealed that they were indeed associated to repetitive tasks. As a result, several recommendations have been developed for the design and arrangement of workstations, as well as the use of tools and equipment to ultimately alleviate or reduce WMSDs (McCauley Bush, 2011).

In international literature there is variability in the terminology related to WMSD. Table 1 presents some of the terms found in literature (in English) and, when identified, the countries where such designation is used. Of thing to be noted is that several of these designations are intended to translate the relationship between the disorder and the suspected causal factor or mechanism of injury.

Also the classification of the conditions allows the scientific community to understand how to treat the conditions, as well as provides information that engineers can utilize to design processes and equipment to mitigate the risk factors (McCauley Bush, 2011).

Designation	Country
Cervicobrachial Syndrome	Japan, Sweden
Cumulative Trauma Disorder	USA
Occupational Cervicobrachial Disorder	Japan, Sweden
Occupational Overuse Syndrome	Australia
Repetitive Strain Injury	Australia, Canada, Netherlands
Work-Related Neck and Upper Limb Disorders; Work-Related Upper Limb Disorders	United Kingdom
Work-Related Musculoskeletal Disorders	World
Repetitive stress injury; Repetitive motion injuries	-

Table 1. WMSD designation (adapted from Nunes, 2003)

2.1 WMSD risk factors

The strong correlation between the incidence of WMSD and the working conditions is well known, particularly the physical risk factors associated with jobs e.g., awkward postures, high repetition, excessive force, static work, cold or vibration. Work intensification and stress and other psychosocial factors also seem to be factors that increasingly contribute to the onset of those disorders (EU-OSHA 2008; EU-OSHA 2011; HSE 2002; EUROFUND, 2007).

As referred WHO attributes a multifactorial etiology to WMSD, which means that these disorders appear as consequence of the worker exposure to a number of work related risk factors (WHO, 1985).

Besides risk factors related to work other risk factors contribute to its development, namely factors intrinsic to the worker and factors unrelated to work. A risk factor is any source or situation with the potential to cause injury or lead to the development of a disease. The variety and complexity of the factors that contribute to the appearance of these disorders explains the difficulties often encountered, to determine the best suited ergonomic intervention to be accomplished in a given workplace, to control them.

Moreover, despite all the available knowledge some uncertainty remains about the level of exposure to risk factors that triggers WMSD. In addition there is significant variability of individual response to the risk factors exposure.

The literature review and epidemiological studies have shown that in the genesis of the WMSD three sets of risk factors can be considered (Bernard, 1997; Buckle & Devereux, 1999; Nunes, 2009a):

- Physical factors - e.g., sustained or awkward postures, repetition of the same movements, forceful exertions, hand-arm vibration, all-body vibration, mechanical compression, and cold;
- Psychosocial factors - e.g., work pace, autonomy, monotony, work/rest cycle, task demands, social support from colleagues and management and job uncertainty;
- Individual factors - e.g., age, gender, professional activities, sport activities, domestic activities, recreational activities, alcohol/tobacco consumption and, previous WMSD.

In order to evaluate the possibility of an employee develop WMSD it is important to include all the relevant activities performed both at work and outside work. Most of the WMSD risk factors can occur both at work and in leisure time activities.

Risk factors act simultaneously in a synergistic effect on a joint or body region. Therefore to manage risk factors it is advisable and important to take into account this interaction rather than focus on a single risk factor. Due to the high individual variability it is impossible to estimate the probability of developing WMSD at individual level. As physicians usually say 'There are no diseases, but patients.'

2.1.1 Physical factors

A comprehensive review of epidemiological studies was performed to assess the risk factors associated with WMSDs (NIOSH, 1997). The review categorized WMSDs by the body part impacted including (1) neck and neck-shoulder, (2) shoulder, (3) elbow, (4) hand-wrist, and (5) back. The widely accepted physical or task-related risk factors include repetition, force, posture, vibration, temperature extremes, and static posture (NIOSH, 1997; McCauley Bush, 2011)

The physical risk factors are a subset of work related risk factors including the environment and biomechanical risk factors, such as posture, force, repetition, direct external pressure (stress per contact), vibration and cold. Another risk factor that affects all risk factors is duration. Since WMSD develop associated with joints, it is necessary that each of these risk factors is controlled for each joints of the human body. In Table 2 a compilation of physical risk factors by body area are presented.

2.1.2 Psychosocial factors

Psychosocial risk factors are non biomechanical risk factors related with work. The work-related psychosocial factors are subjective perceptions that workers have of the organizational factors, which are the objective aspects of how the work is organized, is supervised and is carried out (Hagberg et al., 1995). Although organizational and psychosocial factors may be identical, psychosocial factors include the worker emotional perception. Psychosocial risk factors are related with work content (eg, the work load, the task monotony, work control and work clarity), its organizational characteristics (for example, vertical or horizontal organizational structure), interpersonal relationships at work (e.g., relations supervisor-worker) and financial / economic aspects (eg, salary, benefits and equity) and social (e.g., prestige and status in society) (NIOSH, 1997). Psychosocial factors cannot be seen as risk factors that, by themselves, led to the development of WMSDs (Gezondheidsraad, 2000). However, in combination with physical risk factors, they can increase the risk of injuries, which has been confirmed by experience. Thus, if the psychological perceptions of the work are negative, there may be negative reactions of physiological and psychological stress. These reactions can lead to physical problems, such as muscle tension. On the other hand, workers may have an inappropriate behaviour at work, such as the use of incorrect working methods, the use of excessive force to perform a task or the omission of the rest periods required to reduce fatigue. Any these conditions can trigger WMSDs (Hagberg et al. 1995).

2.1.3 Individual or personal risk factors

The field of ergonomics does not attempt to screen workers for elimination as potential employees. The recognition of personal risk factors can be useful in providing training, administrative controls, and awareness. Personal or individual risk factors can impact the likelihood for occurrence of a WMSD (McCauley-Bell & Badiru, 1996a; McCauley-Bell & Badiru, 1996b). These factors vary depending on the study but may include age, gender, smoking, physical activity, strength, anthropometry and previous WMSD, and degenerative joint diseases (McCauley Bush, 2011).

Gender (McCauley Bush, 2011)

Women are three times more likely to have CTS than men (Women.gov, 2011). Women also deal with strong hormonal changes during pregnancy and menopause that make them more likely to suffer from WMSD, due to increased fluid retention and other physiological conditions. Other reasons for the increased presence of WMSDs in women may be attributed to differences in muscular strength, anthropometry, or hormonal issues. Generally, women are at higher risk of the CTS between the ages of 45 and 54. Then, the risk increases for both men and women as they age. Some studies have found a higher prevalence of some WMSDs in women (Bernard et al., 1997; Chiang et al., 1993; Hales et al., 1994), but the fact that more women are employed in hand-intensive jobs may account for the greater number of reported work-related MSDs among women. Likewise, (Byström et al., 1995) reported that men were more likely to have deQuervain's disease than women and attributed this to more frequent use of power hand tools. Whether the gender difference seen with WMSDs in some studies is due to physiological differences or differences in exposure is not fully understood.

Neck and neck/shoulder	Shoulder	Elbow	Hand-wrist	Lower back	Lower limbs
<p>Repetitive neck movements</p> <p>Repeated arm or shoulder motions that generate loads to the neck-shoulder area (i.e., trapezius muscle)</p> <p><i>Repetition</i></p>	<p>Cyclical flexion, extension, abduction, or rotation of the shoulder joint</p>	<p>Cyclical flexion and extension of the elbow or cyclical Pronation, supination, and extension, and flexion of the wrist that generates loads to the elbow-forearm region</p>	<p>Repetitive hand-finger or wrist movements (i.e., hand gripping)</p> <p>Wrist extension-flexion, ulnar-radial deviation, and supination or pronation</p> <p>Frequent repetitions have been defined as a cycle time <30 s or 50% of the task cycle spent performing the same activity (Silverstein et al., 1987).</p>		<p>Kneeling/ squatting</p> <p>Climbing stairs or ladders</p> <p>Heavy lifting</p> <p>Walking/standing</p>
<p>Extreme head or neck postures</p> <p>Static postures of the head and/or neck</p> <p><i>Posture</i></p>	<p>When the arm is flexed, abducted, or extended, such that the angle between the torso and the upper arm increases</p>	<p>Repeated pronation, supination, flexion, or extension of the wrist, either singly or in combination with extension and flexion of the elbow</p>	<p>No neutral posture of the hand, wrist and/ or fingers-wrist flexion or extension, ulnar or radial deviation</p> <p>full hand grip, and pinch grip</p>	<p>Static - isometric positions where very little movement occurs, along with cramped or inactive postures</p> <p>Prolonged standing or sitting (sedentary work)</p> <p>No-neutral trunk postures (related to bending and twisting) in extreme positions or at extreme angles</p>	

Table 2. WMSD physical risk factors by body area

	Neck and neck/shoulder	Shoulder	Elbow	Hand-wrist	Lower back	Lower limbs
<i>Force</i>	Forceful exertions involving the upper body that generates loads to the trapezius and neck muscles	Shoulder abduction, flexion, extension, or rotation to exert force	Strenuous activities involving the forearm extensors or flexors, which can generate loads to the elbow-forearm region	Forceful exertions performed by the hand, with or without a hand tool, during manipulative task activities	The physical stress that results from work done in transferring objects from one plane to another Forceful movements such as pulling, pushing, or other efforts	
<i>Vibration</i>		Low- or high-frequency vibration generally as a result of hand tools		Manual work involving vibrating power hand tools	Whole Body Vibration transferred to the body as a whole (in contrast to specific body regions), usually through a supporting system such as a seat or platform	
<i>Cold</i>				Workers may exert more force than necessary, affecting muscles, soft tissues, and joints May require gloves that have been shown to impact sensation thus leading to additional force exertion		

Table 2. (continued) WMSD physical risk factors by body area

To differentiate the effect of work risk factors from potential effects that might be attributable to biological differences, researchers must study jobs that men and women perform relatively equally.

Physical Activity (McCauley Bush, 2011)

Studies on physical fitness level as a risk factor for WMSDs have produced mixed results. Physical activity may cause injury. However, the lack of physical activity may increase susceptibility to injury, and after injury, the threshold for further injury is reduced. In construction workers, more frequent leisure time was related to healthy lower backs and severe low-back pain was related to less leisure time activity (Holmström et al., 1992). On the other hand, some standard treatment regimes have found that musculoskeletal symptoms are often relieved by physical activity. National Institute for Occupational Safety and Health (NIOSH, 1991) stated that people with high aerobic capacity may be fit for jobs that require high oxygen uptake, but will not necessarily be fit for jobs that require high static and dynamic strengths and vice versa.

Strength (McCauley Bush, 2011)

Epidemiologic evidence exists for the relationship between back injury and weak back strength in job tasks. Chaffin & Park (1973) found a substantial increase in back injury rates in subjects performing jobs requiring strength that was greater or equal to their isometric strength-test values. The risk was three times greater in weaker subjects. In a second longitudinal study, Chaffin et al. (1977) evaluated the risk of back injuries and strength and found the risk to be three times greater in weaker subjects. Other studies have not found the same relationship with physical strength. Two prospective studies of low-back pain reports (or claims) of large populations of blue collar workers (Battie et al., 1989; Leino, 1987) failed to demonstrate that stronger workers (defined by isometric lifting strength) are at lower risk for lowback pain claims or episodes.

Anthropometry (McCauley Bush, 2011)

Weight, height, body mass index (BMI) (a ratio of weight to height squared), and obesity have all been identified in studies as potential risk factors for certain WMSDs, particularly CTS and lumbar disc herniation. Vessey et al. (1990) found that the risk for CTS among obese women was double that of slender women. The relationship of CTS and BMI has been suggested to be related to increased fatty tissue within the carpal canal or to increased hydrostatic pressure throughout the carpal canal in obese persons compared with slender persons (Werner et al, 1994). Carpal tunnel canal size and wrist size has been suggested as a risk factor for CTS; however, some studies have linked both small and large canal areas to CTS (Bleecker, et al., 1985; Winn & Habes, 1990). Studies on anthropometric data are conflicting, but in general indicate that there is no strong correlation between stature, body weight, body build, and low back pain. Obesity seems to play a small but significant role in the occurrence of CTS.

Smoking (McCauley Bush, 2011)

Several studies have presented evidence that smoking is associated with low-back pain, sciatica, or intervertebral herniated disc (Finkelstein, 1995; Frymoyer et al., 1983; Kelsey et al., 1990; Owen & Damron, 1984; Svensson & Anderson, 1983); whereas in others, the

relationship was negative (Frymoyer, 1991; Hildebrandt, 1987; Kelsey et al., 1990; Riihimäki et al., 1989). Boshuizen et al. (1993) found a relationship between smoking and back pain only in those occupations that required physical exertion. In this study, smoking was more clearly related to pain in the extremities than to pain in the neck or the back. Deyo & Bass (1989) noted that the prevalence of back pain increased with the number of pack-years of cigarette smoking and with the heaviest smoking level. Several explanations for the relationship have been proposed. One hypothesis is that back pain is caused by coughing from smoking.

Coughing increases the abdominal pressure and intradiscal pressure, thereby producing strain on the spine. Several studies have observed this relationship (Deyo & Bass, 1989; Frymoyer et al., 1980; Troup et al., 1987). Other theories include nicotine-induced diminished blood flow to vulnerable tissues (Frymoyer et al., 1983), and smoking-induced diminished mineral content of bone causing microfractures (Svensson & Andersson, 1983).

2.1.4 Interaction among risk factors

All risk factors interact among each other. For example, the stress felt by a worker may be influenced by the physical demands of the task, the psychological reaction to this requirement, or by both.

Once the requirement of the task reaches a high value, the worker may have stress reactions and biological and behavioral unsuitable reactions. As these reactions are more frequent and occur over an extended period they cause health problems. These health problems reduce the 'resistance' of individuals to cope with the subsequent demands of work, thus increasing the possibility of occurrence of WMSDs. As mentioned, the duration of exposure to risk factors is one of the parameters that must be taken into account when a risk assessment is performed. For example, the heuristic model dose-response (Figure 1) to cumulative risk factors in repetitive manual work, proposed by Tanaka McGlothlin, underlines the role of the duration of the activity in the development of musculoskeletal disorders of the hand / wrist (Tanaka & McGlothlin, 2001).

In the figure it's possible to observe the interaction of the following risk factors: force, repetition and wrist posture with exposure duration. In order to keep workers operating in a safe area an increase in exposure duration should be accompanying with a reduction of the other risk factors.

2.2 Models of WMSD pathophysiologic mechanisms

As mentioned before the term WMSD usually refers to disorders caused by a combination of risk factors that act synergistically on a joint or body region, over time. Until now the biological pathogenesis associated with the development of the majority of the WMSD is unknown. However several models have been proposed to describe the mechanisms that lead to the development of WMSDs, ie how different risk factors act on human body. See for instance the models proposed by (Armstrong et al. 1993; NRC, 1999; NRC & IOM 2001). Such models provide a guide to ergonomic interventions aiming to control the development of WMSDs.

The integrated model presented in Figure 2 combines the theories and models that accounted for the various possible mechanisms and pathways (Karsh, 2006). At the top of the model are the factors relating to workplace that determine exposure to WMSD risk factors ie, the work organization, the company socio-cultural context and the environment surrounding the workplace.

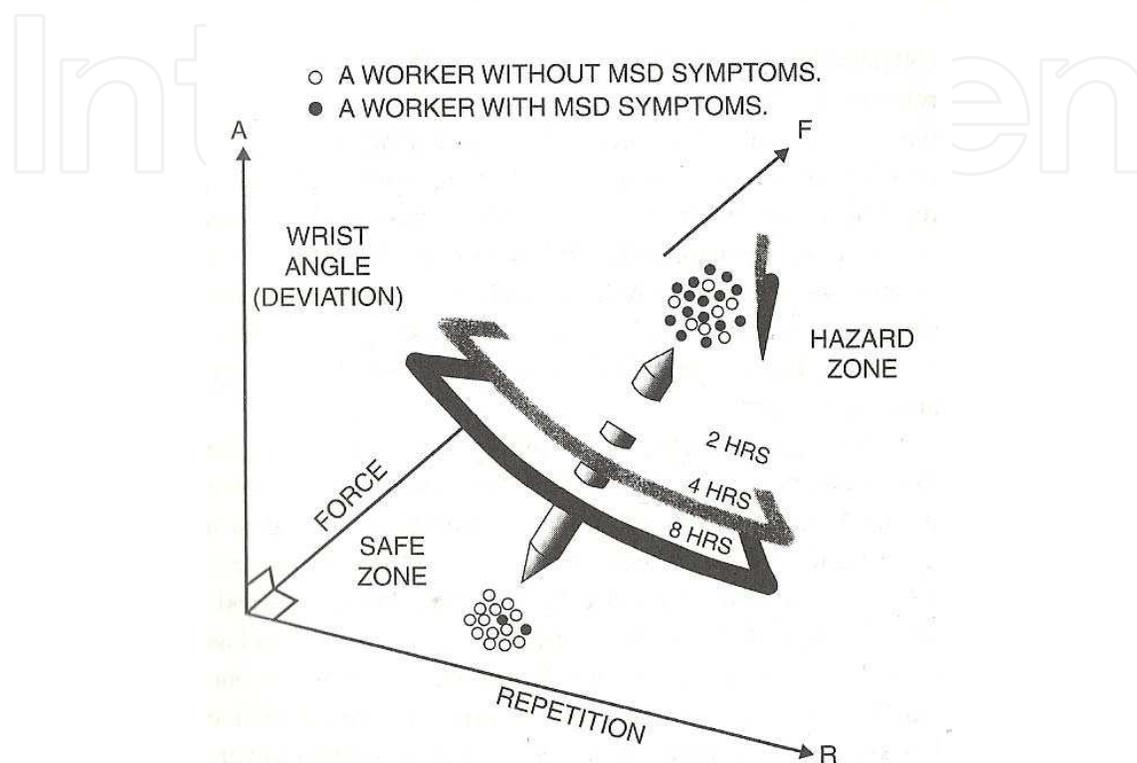


Fig. 1. Risk factors interaction (Tanaka & McGlothlin, 2001).

The mechanisms or pathways that can lead to development of WMSDs are numbered from 1 to 36 in the figure, and are explained below:

- '1' indicates that the social and cultural context of the organization influences the way work is organized;
- '2' shows that the social and cultural context of the organization may have a direct impact on psychological demands of work, through for example, the safety climate of the company;
- '3' and '4' represent the direct impact of work organization on the physical and psychological work demands, also indicating that the impact of the social / cultural context have in physical and psychological demands is mediated by the organization of work. Since the organization of work can be defined as the objective nature of the work, it determines the physical and psychological characteristics of work;
- '5' and '6' shows that the work environment, for example, lighting conditions, the noise, vibration or temperature may also influence directly the physical demands and psychological work demands. For example, reflections due to inadequate lighting conditions in a computer screen, can influence the posture adopted by the worker, in order not to be affected by the reflections;

- '7' is a reciprocal pathway between the physical and psychological demands of work, which indicates that these two types of requirements influence each other. For example, a job highly repetitive can influence the perception of low control over their activities that workers must have;
- '8' represents the direct impact of the physical work demands on physical strain. The mechanism by which this occurs and, consequently led to the development of WMSDs can be through over-exertion, accumulated charge, fatigue or changes in work style;
- '9' indicates the psychological tension generated by the physical demands;
- '10' shows that the psychological work demands can influence the psychological strain. These requirements may have a direct impact on psychological strain if the requirements cause psychological stress or anxiety. These influences may be due to changes in work style, increased muscle tension or psychological stress.
- '11' and '12' show that the physical and psychological demands of work can have a direct impact on the individual characteristics of workers, through mechanisms of adaptation such as improving their physical or psychological capacity;
- '13' is a reciprocal pathway that shows that the physical and psychological strains can influence each other. The psychological strain may impact physical strain by increasing the muscle tension, while the physical strain can influence psychological strain. Individual characteristics such as physical and psychological tolerance to fatigue and resistance to stress may moderate many of the above relationships. Thus:
- '14' physical capacity may moderate the relationship between the physical work demands and physical strain;
- '15' coping mechanisms may moderate the relationship between psychological work demands and physiological strain;
- '16' capacity and internal tolerances can impact the extent to which physical and psychological strain affect each other;
- '17' and '18' indicate that the physical and psychological strain can cause changes in physiological responses, which can provide new doses for other physical and psychological responses;
- '19', '20', '21', '35' indicate that the individual characteristics, the work organization, and the physical and psychological strain and the related physiological responses may have an impact in the detection of symptoms through mechanisms related to increased sensitivity;
- '22' represents the perception, identification and attribution of symptoms to 'something' by workers;
- '23' represents the fact that the symptoms can lead to WMSD diagnosis;
- '24' indicates that, even without symptoms, a WMSD may be present;
- '25', '26', '27' and '28' represent the fact that the existence of WMSDs may have effects on psychological and physical strain and / or the physical and psychological work demands, since the existence of a WMSD, can lead to modification in the way a worker performs his work, or increase psychological stress;
- '29', '30', '31' and '32' indicate that the mere presence of symptoms can lead a worker to modify the way he performs his work thus contributing to stress;
- '33' and '34' respectively indicate that the perception of symptoms or the presence of WMSDs can lead to redesign of the work, which has an impact on work organization.

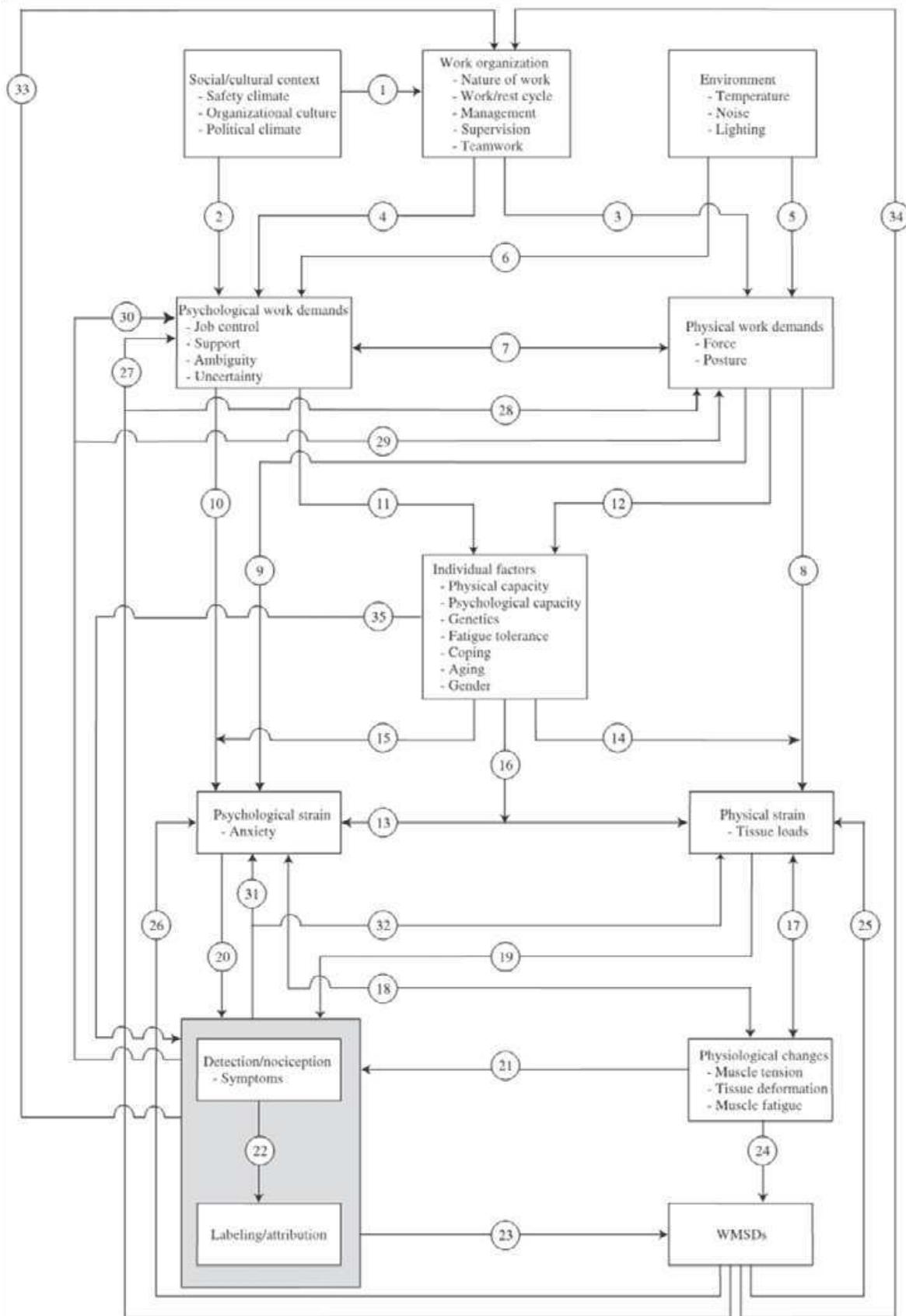


Fig. 2. WMSD integrated model (Karsh, 2006).

As referred non-professional activities can also contribute to the development of WMSD, thus we can add to this model a pathway '36' that represent sport or domestic activities. The pathway should impact the 'physical strain' box.

2.3 The most relevant WMSD and risk factors

WRMD are classified according to the affected anatomical structure (Putz-Anderson, 1988; Pujol, 1993; Hagberg et al., 1995):

- Tendon - include inflammation of the tendons and / or their synovial sheaths. These disorders are usually identify as tendonitis, which is the inflammation of tendons; tenosynovitis, which are injuries involving tendons and their sheaths, and synovial cysts, which are the result of lesions in the tendon sheath;
- Bursa - its inflammation is designated as bursitis;
- Muscles - muscles fatigue, such as, in Tension Neck Syndrome;
- Nerve - involve the compression of a nerve, such as the Carpal Tunnel Syndrome;
- Vascular - affects the blood vessels, as in vibration syndrome.

Table 3 shows the WMSDs that will be addressed in this document, organized according to region of the body where they occur and the anatomical structure affected.

The characterization of several WRMD is provided in the following paragraphs.

Tension Neck Syndrome

The Tension Neck Syndrome is a term that designates a set of muscle pain, accompanied by increased sensitivity and stiffness in the neck and shoulders, often registering muscle spasms. This syndrome is most common in women than in men. It has not been possible to determine whether this difference in incidence is due to genetic factors or exposure to different risk factors, both professional and unprofessional, characteristic of females, (Hagberg, et al., 1995). Epidemiological studies carried out by Bernard (NIOSH, 1997) revealed the existence of a causal relationship between the performance of highly repetitive work and the existence of this type of injury. The introduction of data in computer terminals is an example of a work situation where constrained arms and head postures occur during work.

Back Injuries (McCauley Bush, 2011)

The back is the most frequently injured part of the body (22% of 1.7 million injuries) (NSC, Accident Facts, 1990) with overexertion being the most common cause of these injuries. However, many back injuries develop over a long period of time by a repetitive loading of the discs caused by improper lifting methods or other exertions.

In fact, 27% of all industrial back injuries are associated with some form of lifting or manual material handling. These injuries are generally repetitive and result after months or years of task performance. Often injuries that appear to be acute are actually the result of long-term impact. The discs of the back vary in size, are round, rubber-like pads filled with thick fluid, which serve as shock absorbers. All the forces that come down the spine compress these discs, as a result of continuous and repetitive squeezing. In some instance disks can rupture and bulge producing pressure on the spinal nerve resulting in back pain.

		WMSD							
Body part	Affected structure	Neck	Shoulder	Elbow	Wrist/ Hand	Lumbar area	Hip/ Thigh	Knee	Leg/ Foot
	Tendons and sheaths		Shoulder Tendonitis	Epicondylitis	De Quervain Disease Tenosynovitis Wrist / Hand Synovial Cyst Trigger Finger		Piriformis Syndrome	Pre-patellar Tendonitis Shin splints Infra-patellar Tendonitis	Achilles Tendonitis
	Bursa/ capsule		Shoulder Bursitis Frozen Shoulder (adhesive capsulitis)	Olecranon Bursitis					
	Muscles	Tension Neck Syndrome					Trochanteritis		
	Nerves	Cervical Spine Syndrome	Thoracic Outlet Syndrome	Radial Tunnel Syndrome Cubital Tunnel Syndrome	Carpal Tunnel Synd. Guyon's Canal Synd. Hand-Arm Syndrome (Raynaud Syndrome) Hypothenar Hammer Syndrome	Low Back Pain	Piriformis Syndrome		Varicose veins Venous disorders
	Blood vessels								
	Bone/ cartilage						Sacroiliac Joint Pain	Pre-patellar Tendonitis	

Table 3. Most relevant WMSD by body part and affected anatomical structure (adapted from Nunes, 2003)

Carpal Tunnel Syndrome (McCauley Bush, 2011)

Perhaps the most widely recognized WMSD of the hand and forearm region is carpal tunnel syndrome (CTS), a condition whereby the median nerve is compressed when passing through the bony carpal tunnel (wrist). The carpal tunnel comprises eight carpal bones at the wrist, arranged in two transverse rows of four bones each. The tendons of the forearm muscles pass through this canal to enter the hand and are held down on the anterior side by fascia, called flexor and extensor retinacula, which are tight bands of tissue that protect and restrain the tendons as they pass from the forearm into the hand. If these transverse bands of fascia were not present, the tendons would protrude when the hand is flexed or extended (Spence, 1990). The early stages of CTS result when there is a decrease in the effective cross section of the tunnel caused by the synovium swelling and the narrowing of the confined space of the carpal tunnel. Subsequently, the median nerve, which accompanies the tendons through the carpal tunnel, is compressed and the resulting condition is CTS.

Early symptoms of CTS include intermittent numbness or tingling and burning sensations in the fingers. More advanced problems involve pain, wasting of the muscles at the base of the thumb, dry or shiny palms, and clumsiness. Many symptoms first occur at night and may be confined to a specific part of the hand. If left untreated, the pain may radiate to the elbows and shoulders.

Tendonitis (McCauley Bush, 2011)

Tendonitis, an inflammation of tendon sheaths around a joint, is generally characterized by local tenderness at the point of inflammation and severe pain upon movement of the affected joint. Tendonitis can result from trauma or excessive use of a joint and can afflict the wrist, elbow (where it is often referred to as 'tennis elbow'), and shoulder joints.

Tenosynovitis (McCauley Bush, 2011)

Tenosynovitis is a repetition-induced tendon injury that involves the synovial sheath. The most widely recognized tenosynovitis is deQuervain's disease. This disorder affects the tendons and sheaths on the side of the wrist and at the base of the thumb.

Intersection Syndrome and deQuervain's Syndrome (McCauley Bush, 2011)

Intersection syndrome and deQuervain's syndrome occur in hand-intensive workplaces.

These injuries are characterized by chronic inflammation of the tendons and muscles on the sides of the wrist and the base of the thumb. Symptoms of these conditions include pain, tingling, swelling, numbness, and discomfort when moving the thumb.

Trigger Finger (McCauley Bush, 2011)

If the tendon sheath of a finger is aggravated, swelling may occur. Sufficient amounts of swelling may result in the tendon becoming locked in the sheath. At this point, if the person attempts to move the finger, the result is a snapping and jerking movement.

This condition is called trigger finger. Trigger finger occurs to the individual or multiple fingers and results when the swelling produces a thickening on the tendon that catches as it runs in and out of the sheath. Usually, snapping and clicking in the finger arises with this disorder. These clicks manifest when one bends or straightens the fingers (or thumb). Occasionally, a digit will lock, either fully bent or straightened.

Ischemia (McCauley Bush, 2011)

Ischemia is a condition that occurs when blood supply to a tissue is lacking. Symptoms of this disorder include numbness, tingling, and fatigue depending on the degree of ischemia, or blockage of peripheral blood vessels. A common cause of ischemia is compressive force in the palm of the hand.

Vibration Syndrome (McCauley Bush, 2011)

Vibration syndrome is often referred to as white finger, dead finger, or Raynaud's phenomenon. These conditions are sometimes referred to as hand arm vibration (HAV) syndrome. Excessive exposure to vibrating forces and cold temperatures may lead to the development of these disorders. It is characterized by recurrent episodes of finger blanching due to complete closure of the digital arteries.

Thermoregulation of fingers during prolonged exposure to cold is recommended, as low temperatures reduce blood flow to the extremities and can exacerbate this condition.

Thoracic Outlet Syndrome (McCauley Bush, 2011)

Thoracic outlet syndrome (TOS) is a term describing the compression of nerves (brachial plexus) and/or vessels (subclavian artery and vein) to the upper limb.

This compression occurs in the region (thoracic outlet) between the neck and the shoulder. The thoracic outlet is bounded by several structures: the anterior and middle scalene muscles, the first rib, the clavicle, and, at a lower point, by the tendon of the pectoralis minor muscle. The existence of this syndrome as a true clinical entity has been questioned, because some practitioners suggest that TOS has been used in error when the treating clinician is short on a diagnosis and unable to explain the patient's complaints. Symptoms of TOS include aching pain in the shoulder or arm, heaviness or easy fatigability of the arm, numbness and tingling of the outside of the arm or especially the fourth and fifth fingers, and finally swelling of the hand or arm accompanied by finger stiffness and coolness or pallor of the hand.

Ganglion Cysts (McCauley Bush, 2011)

Ganglion is a Greek word meaning 'a knot of tissue.' Ganglion cysts are balloon like sacs, which are filled with a jelly-like material. The maladies are often seen in and around tendons or on the palm of the hand and at the base of the finger. These cysts are not generally painful and with reduction in repetition often leave without treatment.

Lower limbs WMSD

Lower limb WMSD are currently a problem in many jobs, they tend to be related with disorders in other areas of the body. The epidemiology of these WMSD has received until now modest awareness, despite this there is appreciable evidence that some activities (e.g., kneeling/ squatting, climbing stairs or ladders, heavy lifting, walking/standing) are causal risk factors for their development. Other causes for acute lower limb WMSD are related with slip and trip hazards (HSE, 2009). Despite the short awareness given to this type of WMSD they deserve significant concern, since they often are sources of high degrees of immobility and thereby can substantially degrade the quality of life (HSE, 2009). The most common lower limb WMSD are (HSE, 2009):

- Hip/thigh conditions - Osteoarthritis (most frequent), Piriformis Syndrome, Trochanteritis, Hamstring strains, Sacroiliac Joint Pain;
- Knee / lower leg - Osteoarthritis, Bursitis, Beat Knee/Hyperkeratosis, Meniscal Lesions, Patellofemoral Pain Syndrome, Pre-patellar Tendonitis, Shin Splints, Infra-patellar Tendonitis, Stress Fractures;
- Ankle/foot - Achilles Tendonitis, Blisters, Foot Corns, Halux Valgus (Bunions), Hammer Toes, Pes Traverse Planus, Plantar Fasciitis, Sprained Ankle, Stress fractures, Varicose veins, Venous disorders.

Non-specific WMSD

Non-specific WMSD are musculoskeletal disorders that have ill-defined symptoms, i.e. the symptoms tend to be diffuse and non-anatomical, spread over many areas: nerves, tendons and other anatomical structures (Ring et al. 2005). The symptoms involve pain (which becomes worse with activity), discomfort, numbness and tingling without evidence of any discrete pathological condition.

2.4 Summary of WMSD, symptoms and occupational risk factors

The assessment of WMSD's can be done using multiple checklists, subjective and objective assessments. An efficient approach is to identify occupational risk factors and make efforts to remove them from task. Where the risk factors cannot be removed the impact should be reduced and mitigation strategies employed to reduce the likelihood for injury. Administrative controls such as more frequent rest breaks, task sharing or rotation between jobs. Table 4 provides a summary of common WMSDs, symptoms and risk factors.

Identified disorders, occupational risk factors and symptoms		
Disorders	Occupational risk factors	Symptoms
Tendonitis/tenosynovitis	Repetitive wrist motions Repetitive shoulder motions Sustained hyper extension of arms Prolonged load on shoulders	Pain, weakness, swelling, burning sensation or dull ache over affected area
Epicondylitis (elbow tendonitis)	Repeated or forceful rotation of the forearm and bending of the wrist at the same time	Same symptoms as tendonitis
Carpal tunnel syndrome	Repetitive wrist motions	Pain, numbness, tingling, burning sensations, wasting of muscles at base of thumb, dry palm
DeQuervain's disease	Repetitive hand twisting and forceful gripping	Pain at the base of thumb
Thoracic outlet syndrome	Prolonged shoulder flexion Extending arms above shoulder height Carrying loads on the shoulder	Pain, numbness, swelling of the hands
Tension neck syndrome	Prolonged restricted posture	Pain

Table 4. Work Related Musculoskeletal Disorders, Symptoms and Risk Factors (Canadian Centre for Occupational Health and Safety, 2011)

3. Procedure for workplace analysis and design (McCauley Bush, 2011)

Job analysis, risk factor assessment, and task design should be conducted to identify potential work-related risks and develop engineering controls, administrative controls, and personal protective resources to mitigate the likelihood of injuries. According to American National Standards Institute (ANSI), this can be accomplished with the following steps (Karwowski & Marras, 1998):

- Collect pertinent information for all jobs and associated work methods.
- Interview a representative sample of affected workers.
- Breakdown a job into tasks or elements.
- Description of the component actions of each task or element.
- Measurement and qualification or quantification of WMSDs (where possible).
- Identification of risk factors for each task or element.
- Identification of the problems contributing to the risk factors.
- Summary of the problem areas and needs for intervention for all jobs and associated new work methods.

These steps can be executed utilizing any combination of scientifically based assessment techniques including surveys, electronic measurement equipment, software tools, and analysis approaches.

4. Ergonomic tools for assessing WMSD risk factors

A diversity of ergonomic tools has been developed in order to help in the identification of WMSD risk factors and assessing the risk present on workstations. Some of the tools already developed are, for instance, OWAS (Karhu et al. 1977) (and the associated software WinOWAS (Tiilikainen, 1996)), RULA (McAtamney & Corlett, 1993), Strain Index (Moore and Garg 1995), NIOSH (Waters et al. 1993), (NIOSH, 1994), OCRA (Occhipinti, 1998), (Occhipinti & Colombini 2007), Quick Exposure Check (Li & Buckle, 1999), a fuzzy predictive model developed by McCauley Bell (McCauley-Bell & Badiru, 1996a) and FAST ERGO_X (Nunes, 2009a). The two systems developed by the chapter authors will be presented below.

4.1 Fuzzy risk predictive model

The development of quantitative model for industry application was the focus of research that produced the McCauley Bush and Badiru approach to prediction of WMSD risk. This model is intended for use as a method obtain the likelihood for WMSD risk for a specific individual performing a task at a given organization. The research identified three broad categories (modules) for WMSD risk factors as task-related, personal-related and organizational-related classifications. Within each of these categories, additional factors were identified. The items identified as risk factors for each of the three modules (task, personal and organizational) were evaluated for relative significance. The relative significance (priority weights) for the risk factors in the task-related and personal modules are listed in Tables 5 and Table 8, respectively. The levels of existence for each factor within the task related category is also shown in Table 6.

Ranking	Factor	Relative Weight
1	Awkward joint posture	0.299
2	Repetition	0.189
3	Hand tool use	0.180
4	Force	0.125
5	Task duration	0.124
6	Vibration	0.083

Table 5. AHP Results: Task-Related Risk Factors

	Posture	Repetition	Hand Tool	Force	Task Duration	Vibration
High	1.0	1.0	1.0	1.0	1.0	1.0
Medium	0.5	0.5	0.5	0.5	0.5	0.5
Low	0.2	0.2	0.2	0.2	0.2	0.2
None	0.0	0.0	0.0	0.0	0.0	0.0

Table 6. Levels of Existence for each factor

In the evaluation the organizational risk factors, equipment was the most significant factor. The term equipment refers to the degree of automation for the machinery being used in the task under evaluation. The relative significance and for each of the risk factors is listed in Table 6. This module evaluated the impact of seven risk factors. However, upon further analysis and discussion, the awareness and ergonomics program categories were combined because according to the experts and the literature, one of the goals of an ergonomics program is to provide awareness about the ergonomic risk factors present in a workplace.

Ranking	Factor	Relative Weight
1	Previous CTD	0.383
2	Hobbies and habits	0.223
3	Diabetes	0.170
4	Thyroid problems	0.097
5	Age	0.039
6	Arthritis or Degenerative Joint Disease (DJD)	0.088

Table 7. AHP Results: Personal Risk Factors

	Previous CTD	Hobbies & Habits	Diabetes	Thyroid Condition	Age	Arthritis or DJD
High	1.0	1.0	1.0	1.0	1.0	1.0
Medium	0.5	0.5	0.5	0.5	0.5	0.5
Low	0.2	0.2	0.2	0.2	0.2	0.2
None	0.0	0.0	0.0	0.0	0.0	0.0

Table 8. Levels of Existence for Personal Risk Factors

Ranking	Factor	Relative Weight
1	Equipment	0.346
2	Production rate/layout	0.249
3	Ergonomics program	0.183
4	Peer influence	0.065
5	Training	0.059
6	CTD level	0.053
7	Awareness	0.045

Table 9. AHP Results: Organizational Risk Factors

	Equipment	Production rate/layout	Ergonomics program	Peer influence	Training	CTD level	Awareness
High	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Medium	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Low	0.2	0.2	0.2	0.2	0.2	0.2	0.2
None	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 10. Levels of Existence for Organizational Risk Factors

After the factors within the categories (or modules) were compared, analytic Hierarchy Processing (AHP) analysis was conducted to determine the relative significance of each of the modules: task, personal and organizational characteristics. The relative significance (priority weights) obtained for the task, personal, and organizational characteristics are listed in Table 11. The task characteristics module received a relative weight of 0.637. The personal characteristics module had a relative weight of 0.258, less than half of the relative weight of the task characteristics module. Finally, the organizational characteristics module received the smallest relative weight, 0.105.

Ranking	Module	Relative Weight
1	Task	0.637
2	Personal	0.258
3	Organizational	0.105

Table 11. AHP Results: Module Risk Comparison

Determination of Aggregate Risk Level

After the linguistic risk and the relative significance are generated an aggregated numeric value is obtainable. Equation 1 represents the model for the calculation of the numeric risk value for the task module. In Equation 1, the w_i values represent the numeric values obtained from the user inputs for each of the six risk factors and the a_j values represent the relative significance or factor weight obtained from the AHP analysis. The numeric risk levels for the personal and organizational characteristics are represented by Equations 2 and 3, respectively. Likewise, the values of x_i and y_j represent the user inputs while, the b_i and c_j

values represent the AHP weights for the task and organizational characteristics, respectively. These linear equations are based on Fuzzy Quantification Theory I (Terano et al, 1987). The objective of Theory I is to find the relationships between the qualitative descriptive variables and the numerical object variables in the fuzzy groups. An alternative to this approach is to use CTD epidemiological data to establish the regression weights rather than the relative weights were derived from the AHP analysis with the experts. However, the lack of availability of comprehensive data for a regression model prevented the application of regression analysis. The resulting equations represent the numeric risk levels for each category.

Task-Related Risk:

$$R_1 = F(T) = a_1w_1 + a_2w_2 + a_3w_3 + a_4w_4 + a_5w_5 + a_6w_6 \quad (1)$$

Personal Risk:

$$R_2 = F(P) = b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 \quad (2)$$

Organizational Risk:

$$R_3 = F(O) = c_1y_1 + c_2y_2 + c_3y_3 + c_4y_4 + c_5y_5 + c_6y_6 \quad (3)$$

Interpretation of Results

The numeric risk values obtained from each of the modules and the weights obtained from the AHP analysis were used to calculate the overall risk level. This value indicates the risk of injury for the given person, on the evaluated task for the workplace under evaluation (Equation 4). The following equation was used to quantify the comprehensive risk of injury is a result of all three categories:

Comprehensive Risk:

$$Z = d_1R_1 + d_2R_2 + d_3R_3 \quad (4)$$

where,

Z = overall risk for the given situation,

R_1 = the risk associated with the task characteristics,

d_1 = weighting factor for the task characteristics,

R_2 = the risk associated with the personal characteristics,

d_2 = weighting factor for the personal characteristics,

R_3 = the risk associated with the organizational characteristics,

d_3 = weighting factor for the organizational characteristics.

The weighting factors (d_1 , d_2 , d_3) represent the relative significance of the given risk factor category's contribution to the likelihood of injury. These factors were determined through the AHP analysis. The numeric risk levels obtained from the previous equations exist on the interval [0,1]. On this interval 0 represents 'no risk of injury' and 1 represents 'extreme risk of injury'. The interpretation and categorization is shown in Table 12.

Numeric Risk Level	Expected Amount of Risk Associated with Numeric Value
0.00 - 0.20	Minimal risk: Individual should not be experiencing any conditions that indicated musculoskeletal irritation
0.21 - 0.40	Some risk: may be in the very early stages of CTD development. Individual may experience irregular irritation but is not expected to experience regular musculoskeletal irritation
0.41 - 0.60	Average risk: Individual may experience minor musculoskeletal irritation on a regular but not excessive irritation
0.61 - 0.80	High risk: Individual is expected to be experiencing regular minor or major musculoskeletal irritation
0.81 - 1.00	Very high risk: Individual is expected to presently experience ongoing or regular musculoskeletal irritation and/or medical correction for the condition

Table 12. Interpretation and Categorization of aggregate risk levels

4.2 FAST ERGO_X

FAST ERGO_X is a system whose aim is to assist Occupational Health and Safety professionals in the identification, assessment and control of ergonomic risks related with the development of WMSD. It was designed to identify, evaluate and control the risk factors due to ergonomic inadequacies existing in the work system (Nunes, 2009a). This method was developed in Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa, Portugal.

As referred before despite all the available knowledge there remains some uncertainty about the precise level of exposure to risk factors that triggers WMSD. In addition there is significant variability of individual response to the risk factors exposure. Aware that there was yet room for use of alternative approaches and the development of new features, and recognizing the adequacy of applying fuzzy expert systems for dealing with the uncertainty and imprecision inherent to the factors considered in an ergonomic analysis, the fuzzy expert system model for workstation ergonomic analysis, named ERGO_X and a first prototype were developed (Nunes et al. 1998), (Nunes, 2006). The ERGO_X method of workstation ergonomic analysis was subject to a Portuguese patent (Nunes, 2009b). FAST ERGO_X application was then developed based on the ERGO_X model, therefore FAST ERGO_X is a fuzzy expert system. This is an innovative approach that uses Artificial Intelligence concepts. This approach presents some advantages over the classical methods commonly used.

Based on objective and subjective data, the system evaluates the risk factors present in workplaces that can lead to the development of WMSD, and presents the findings of the evaluation. The system also presents recommendations that users can follow to eliminate or at least reduce the risk factors present in the work situation.

The FAST ERGO_X has the following features:

- data collection - supports the user to collect data, directing the collection and the filling of the data, according to the settings of analysis defined by the user and characteristics of the workstations and tasks under analysis;
- risk factors assessment - performs the assessment of risk factors present on the workplace, synthesizing the elements of analysis, presenting the conclusions in graphical or text formats;
- explanations presentation - provides explanations about the results obtained in the ergonomics analysis allowing an easy identification of individual risk factors that contributed to the result displayed;
- advisement - advises corrective or preventive measures to apply to the work situations, since the knowledge base includes a set of recommendations in HTML format, with hyperlinks that enable the navigation to a set of relevant topics related to the issues addressed (for example, risk factors, potential consequences, preventive measures or good practice references).

The use of FAST ERGO_X comprehends three main phases: analysis configuration, data collection and data analysis. These phases are depicted in Figure 3.

The use of the FAST ERGO_X is very flexible. On one hand, because it allows the use of objective and subjective data, separately or combined; on the other hand because it can be used on portable computers, which makes its utilization possible in situ either to collect data, to present the results and to support any decision-making that may be required, for instance due to the need of corrective interventions.

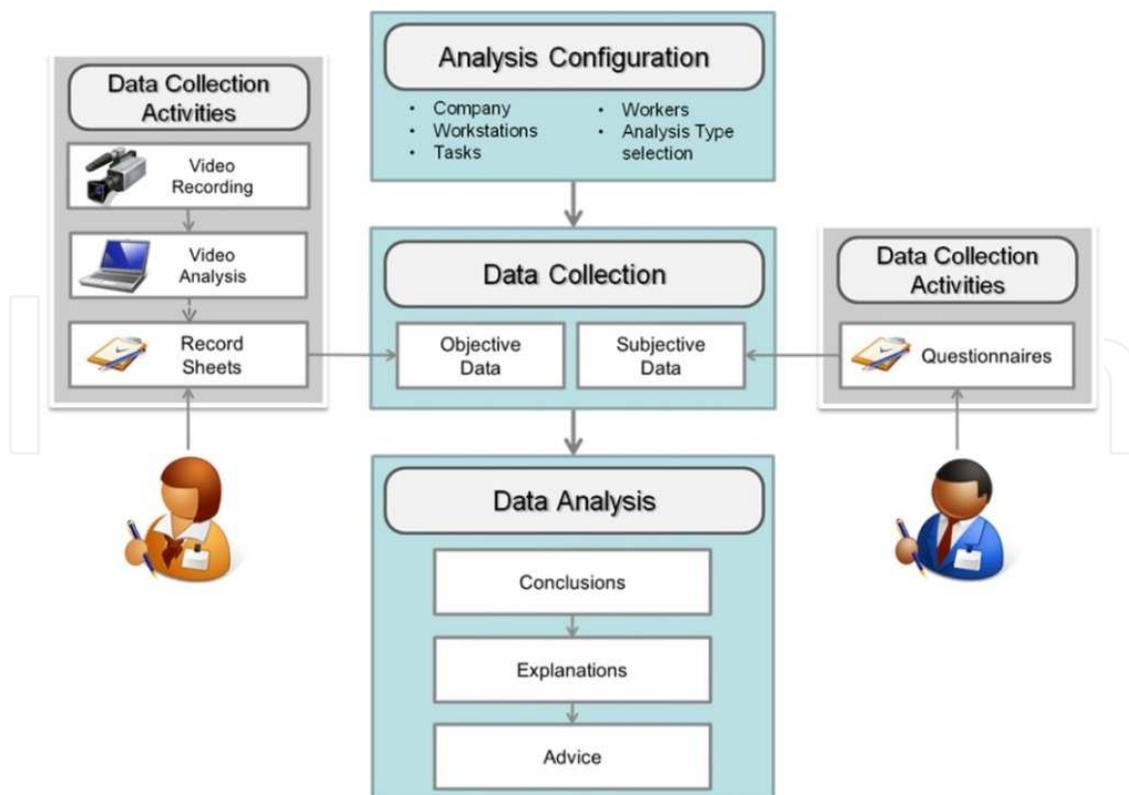


Fig. 3. Activities performed on the analysis of a work situation (Nunes, 2009a).

The forecast capability of the evaluation model allows the use of the system as a WMSD prevention tool creating the opportunity to act on identified risk factors, avoiding the WMSD associated costs and pains.

Finally, FAST ERGO_X can also be used as a tool to promote participatory ergonomics. For instance, the software and the media used for the analysis of the work situations (e.g., video recordings) can be used to support the training of workers in the field of Occupational Safety and Health. This can be achieved either by using the knowledge repository compiled on the knowledge base, by discussing the results of analyses carried out, or by proceeding to critical reviews of the videos collected for the analysis of work situations. Workers' awareness is a key success factor for the reduction of potentially risky behaviours, the identification of inadequate situations, and the development of solutions that help the prevention of WMSD. An example of application can be found in (Nunes, 2009a).

4.3 Additional screening methods for WMSD

Several methods have been developed to screen for, diagnose and treat musculoskeletal disorders. A few examples of screening approaches are discussed below.

4.3.1 Tinel's sign

Jules Tinel, a French neurologist, developed Tinel's Sign in 1915. He noted that after an injury, tapping of the median nerve resulted in a tingling sensation (paresthesia) in the first three and a half digits. Tinel's Sign was not originally associated with carpal tunnel syndrome; it was not until 1957 that George Phalen recognized that Tinel's Sign could be used to diagnose carpal tunnel syndrome (Urbano, 2000). Tinel's method is among the simplest and oldest screening approaches however, the application of this approach requires knowledge in ergonomics and an understanding of the technique. This subjective assessment technique requires input from the subject and can be a useful initial assessment tool however it should be coupled with additional ergonomic assessment tools.

4.3.2 Phalen's test

George S. Phalen, an American hand surgeon, studied patients with carpal tunnel syndrome and recognized that Tinel's Sign could be used to diagnose carpal tunnel syndrome, described it as 'a tingling sensation radiating out into the hand, which is obtained by light percussion over the median nerve at the wrist' (Urbano, 2000). Additionally, Phalen developed a wrist flexing test to diagnose carpal tunnel syndrome. To perform the Phalen's test, the patient should place their elbows on a table, placing the dorsal surfaces of the hands against each other for approximately 3 minutes. The patient should perform this maneuver with the wrists falling freely into their maximum flexion, without forcing the hands into flexion. Patients who have carpal tunnel syndrome will experience tingling or numbness after 1 to 2 minutes, whereas a healthy patient without carpal tunnel syndrome can perform the test for 10 or more minutes before experiencing tingling or numbness (Urbano, 2000).

4.3.3 Durkan test or carpal compression test

In 1991, John A. Durkan, an American orthopaedic surgeon, developed the carpal compression test. In a study of 31 patients with carpal tunnel syndrome, he found that this compression test was more sensitive than the Tinel's or Phalen's tests (Durkan, 1991). The carpal compression test involves directly compressing the median nerve using a rubber atomizer-bulb connected to a pressure manometer from a sphygmomanometer. This direct compression uses a pressure of 150 millimeters of mercury for 30 seconds. The occurrence of pain or paresthesia (tingling) indicates the presence of carpal tunnel syndrome. Durkan also identified an alternate method of performing the compression test by having the examiner apply even pressure with both thumbs to the median nerve in the carpal tunnel (Durkan, 1991).

4.3.4 Vibrometry testing

Vibrometry testing uses sensory perception to determine presence of carpal tunnel syndrome. To utilize this technique, the middle finger is placed on a vibrating stylus. While the evaluator manipulates vibration by altering the frequencies, the patient indicates whether or not they can detect the stylus vibrating. In theory, those with patients with carpal tunnel syndrome will be less sensitive to vibration. However, the effectiveness of vibrometry testing is debated with some studies as it has not conclusively been able to successfully identify carpal tunnel syndrome (Neese & Konz, 1993; Jetzer, 1991), while others show vibrometry testing to be inconclusive (Werne et al., 1994; White et al., 1994).

4.3.5 Nervepace electroneurometer device

Nervepace Electroneurometer is an objective method to test motor nerve conduction and infer the presence of carpal tunnel syndrome. Electrodes for surface stimulation are placed on the median nerve, approximately 3 cm proximal to the distal wrist flexor crease, while recording electrodes are placed on the muscles of the hand. The evaluator then adjusts the stimulus applied to the median nerve until a motor response is detected. The device records the latency between the stimulus and the response times, which the evaluator can use to determine the presence of carpal tunnel syndrome. However, studies have shown that the device can be made ineffective due to skin thickness (callous), peripheral neuropathy, or severe carpal tunnel syndrome. In addition, the American Association of Electrodiagnostic Medicine deemed the Nervepace Electroneurometer as 'flawed,' 'experimental,' and 'not an effective substitute for standard electrodiagnostic studies in clinical evaluation of patients with suspected CTS' (David et al., 2003; Pransky et al., 1997).

5. Conclusion

The objective of this chapter is to provide an introduction to WMSDs, associated risk factors and tools that can be useful in reducing the risks of these injuries. Application of ergonomic, biomechanical and engineering principles can be effective in reducing the risks and occurrence of WMSD. Epidemiological data has demonstrated that occupational risk factors such as awkward postures, highly repetitive activities or handling heavy loads are among the risk factors that studies have shown to damage the bones, joints, muscles, tendons, ligaments, nerves and blood vessels, leading to fatigue, pain and WMSDs. The effective

design of ergonomic tools, equipment, processes and work spaces can have a tremendous effect on the risks and occurrence of WMSD.

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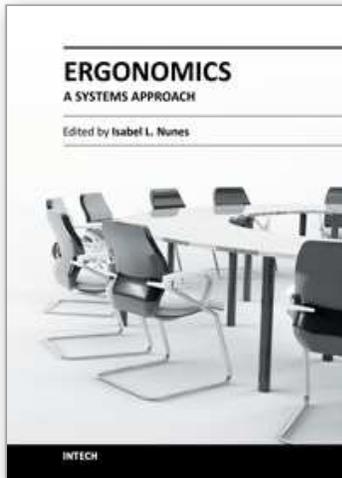
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This book covers multiple topics of Ergonomics following a systems approach, analysing the relationships between workers and their work environment from different but complementary standpoints. The chapters focused on Physical Ergonomics address the topics upper and lower limbs as well as low back musculoskeletal disorders and some methodologies and tools that can be used to tackle them. The organizational aspects of work are the subject of a chapter that discusses how dynamic, flexible and reconfigurable assembly systems can adequately respond to changes in the market. The chapters focused on Human-Computer Interaction discuss the topics of Usability, User-Centred Design and User Experience Design presenting framework concepts for the usability engineering life cycle aiming to improve the user-system interaction, for instance of automated control systems. Cognitive Ergonomics is addressed in the book discussing the critical thinking skills and how people engage in cognitive work.

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University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
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InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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