Health effects of mechanical vibration

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RIASSUNTO. Questo studio illustra i sintomi ed le patologie derivanti dall'esposizione professionale a vibrazioni trasmesse al corpo intero (whole-body vibration, WBV) e a vibrazioni trasmesse al sistema mano-braccio (hand-transmitted vibration, HTV). L'esposizione prolungata a WBV in conducenti di macchine industriali ed agricole o di veicoli per il trasporto pubblico è associata ad una aumentata occorrenza di lombalgie, lombosciatalgie ed alterazioni radiologiche a carico del rachide lombare. Vi è una scarsa evidenza epidemiologica di un aumentato rischio di patologie a carico di altri organi o apparati negli esposti a WBV. L'esposizione a HTV generate da utensili vibranti è associata ad una elevata occorrenza di disturbi e patologie a carico degli apparati vascolare, neurologico e muscolo-scheletrico degli arti superiori. Questo studio fornisce alcune informazioni sulla tipologia e l'entità dell'esposizione professionale a vibrazioni meccaniche nei comparti industriali ed agricolo-forestali dell'Unione Europea. Vengono, infine, discussi gli aspetti connessi con la sorveglianza sanitaria dei lavoratori esposti nel contesto della Direttiva Europea 2002/44/CE sulle vibrazioni meccaniche e delle linee guide elaborate dalla Società Italiana di Medicina del Lavoro e Igiene Industriale.

Parole chiave: vibrazioni mano-braccio; vibrazioni corpo intero; effetti sulla salute; direttive europee; standards ISO.

ABSTRACT. www.gimle.fsm.it
In this study, the health disorders caused by occupational exposure to whole-body vibration (WBV) and hand-transmitted vibration (HTV) are reviewed. Long-term occupational exposure to intense WBV is associated with an increased risk for disorders of the lumbar spine and the connected nervous system. With a lower probability, the neck-shoulder, the gastrointestinal system, the female reproductive organs, the peripheral veins, and the cochleo-vestibular system are also assumed to be affected by WBV. However, there is a weak epidemiologic support for WBV-induced disorders of organ systems other than the lower back. Prolonged exposure to HTV from powered processes or tools is associated with an increased occurrence of symptoms and signs of disorders in the vascular, neurological and osteoarticular systems of the upper limbs. The complex of these disorders is called hand-arm vibration syndrome. This paper provides qualitative and quantitative information on occupational exposure to mechanical vibration in the European Union based on a report by the European Agency for Safety and Health at Work (2000). Protection and health surveillance of vibration-exposed workers are discussed in the context of the European Directive 2002/44/EC on mechanical vibration and the guidelines prepared by the Italian Society of Occupational Medicine and Industrial Hygiene.

Key words: *hand-transmitted vibration; whole-body vibration; health effects; european directive; ISO standards.*

1. Introduction

Mechanical vibration arises from a wide variety of processes and operations performed in industry, mining and construction, forestry and agriculture, and public utilities. ***Whole-body vibration*** occurs when the human body is supported on a surface which is vibrating, e.g. in all forms of transport and when working near some industrial machinery. ***Hand-transmitted vibration*** occurs when the vibration enters the body through the hands, e.g. in various work processes where rotating or percussive power tools or vibrating workpieces are held by the hands or fingers.

The human response to vibration depends mainly on the magnitude, frequency and direction of the vibration signal (7). The magnitude of vibration is quantified by its displacement (m), its velocity (m/s), or its acceleration (m/s^2). For practical convenience, the magnitude of vibration is expressed in terms of an average measure of the acceleration, usually the root mean square value (m/s^2 r.m.s.). The r.m.s. magnitude is related to the vibration energy and hence the vibration injury potential. The frequency of vibration is expressed in cycles per second and it is measured in Hertz (Hz). Biodynamic investigations have shown that the response of the human body to vibration is frequency dependent (7). The adverse health effects of whole-body vibration can occur in the low frequency range from 0.5 to 80 Hz. For hand-transmitted vibration, frequencies from 6.3 to 1250 Hz can provoked disorders in the hand-arm system. Frequencies below about 0.5 Hz can cause motion sickness. To account for these differences in the response of the body to vibration frequency, current standards for human vibration recommend to weight the frequencies of the measured vibration according to the possible deleterious effect associated with each frequency (8, 9). Frequency weightings are required for three orthogonal directions (*x*-, *y*- and *z*-axes) at the interfaces between the body and the vibration.

For the health effects of hand-transmitted vibration on the upper limbs (9), the evaluation of vibration exposure is based on the vibration total value (a_{hv}), a quantity defined as the square root of the sum of the squares (r.m.s.) of the frequency weighted acceleration values (a_{hw}) determined on the three orthogonal axes *x*, *y*, *z*, i.e. $a_{hv}=(a_{hwx}^2+a_{hwy}^2+a_{hwz}^2)$–, ($m/s^2$ r.m.s.). The vibration total value has been also proposed for the evaluation of the health effects of whole-body vibration if no dominant axis of vibration exists (8). For a seated or standing worker, the vibration total value (a_v) for the frequency-weighted accelerations (a_w) of whole-body vibration is calculated as $a_v=(k_x{}^2a_{wx}{}^2+ k_y{}^2a_{wy}{}^2+k_z{}^2a_{wz}{}^2)$–, where k=1.4 for *x*- and *y*-axes and k=1 for *z*-axis. Since it is believed that the health effects of whole-body vibration are influenced by shocks or vibration peaks, the international standard ISO 2631-1 (8) suggests to use the fourth power vibration dose method instead of the second power of the acceleration time history (i.e. r.m.s.) as the basis for averaging. The fourth power vibration dose value (VDV) is expressed in metres per second to the power of 1.75 (i.e. $m/s^{1.75}$).

According to the European Directive 2002/44/EC on mechanical vibration (4), daily vibration exposure is expressed in terms of 8-hour energy-equivalent frequency-weighted acceleration magnitude [A(8) in m/s^2], calculated as $A(8)=A_w(T/T_8)$–, where T is the total daily duration of vibration exposure (hours), and T_8 is the reference duration of 8 hours. For hand-transmitted vibration, A_w is given by a_{hv} as defined in the international standard ISO 5349-1 (9), (see above); for whole-body vibration, A_w is calculated from the highest (r.m.s.) value or the highest vibration dose value (VDV) of the frequency-weighted accelerations determined on three orthogonal axes (i.e. A_w=1.4a_{wx}, 1.4a_{wy}, a_{wz}) in accordance with the international standard ISO 2631-1 (8).

In addition to the physical characteristics of vibration, some other factors are believed to be related to the injurious effects of vibration, such as the duration of exposure (daily, yearly and lifetime cumulative exposures), the pattern of exposure (continuous, intermittent, rest periods), the type of tools, processes or vehicles which produce vibration, the environmental conditions (ambient temperature, airflow, humidity, noise), the dynamic response of the human body (mechanical impedance, vibration transmissibility, absorbed energy), and the individual characteristics (method of tool handling or style of vehicle driving, body posture, health status, training, skill, use of personal protective equipment, individual susceptibility to injury).

Exposure to harmful vibration at the workplace can induce several complaints and health disorders, mainly in the upper limbs and the lower back (1, 6, 7). This study summarises the long-term effects caused by occupational exposure to whole-body vibration and hand-transmitted vibration. In addition to the health effects of vibration, this paper provides qualitative and quantitative information on occupational exposure to mechanical vibration in the European Union (EU) based on a report by the European Agency for Safety and Health at Work (5). Protection and health surveillance of vibration-exposed workers are discussed in the context of the European Directive 2002/44/EC on mechanical vibration (4) and the guidelines prepared by the Italian Society of Occupational Medicine and Industrial Hygiene (2).

2. Whole-body vibration

2.1 General

Long-term occupational exposure to intense whole-body vibration (WBV) is associated with an increased risk for disorders of the lumbar spine and the connected nervous system (6). With a lower probability, the neck-shoulder, the gastrointestinal system, the female reproductive organs, the peripheral veins, and the cochleo-vestibular system are also assumed to be affected by WBV (6). However, there is a weak epidemiologic support for WBV-induced disorders of organ systems other than the lower back. It has been estimated that 4 to 7% of all employees in the U.S., Canada and some European Countries are exposed to potentially harmful WBV (6). In some Countries (e.g. Belgium, France, Germany, The Netherlands) back disorders occurring in workers exposed to WBV are, under certain conditions regarding intensity and duration of exposure, considered to be an occupational disease which is compensable.

The role of WBV in the etiopathogenesis of low back injuries is not yet fully clarified, as driving vehicles involves not only exposure to harmful WBV but also to several ergonomic factors which can affect the spinal system, such as prolonged sitting in a constrained posture, bending forward and frequent twisting of the spine. Moreover, some driving occupations involve heavy lifting and manual handling activities (e.g. drivers of delivery trucks), which are known to strain the lower part of the back. Individual characteristics (age, anthropometric data, smoking habit, constitutional susceptibility), psychosocial factors, and previous back traumas are also recognised as important predictors for low back pain (LBP). Therefore, injuries in the lower back of professional drivers represent a complex of health disorders of multifactorial origin involving both occupational and non-occupational factors. As a result, it is hard to separate the contribution of WBV exposure to the onset and the development of low back troubles from that of other individual and ergonomic risk factors.

2.2 Low back disorders and WBV exposure

In a recent epidemiologic review of the long-term effects of WBV on the lumbar spine (3), crane operators, bus drivers, tractor drivers, and fork-lift truck drivers were found to be the most frequently investigated occupational groups in either cross-sectional or cohort studies. Vibration measurements performed according to ISO 2631-1 showed that vibration magnitude (a_v) varied from 0.25 to 0.67 m/s^2 in cranes, 0.36 to 0.56 m/s^2 in busses, 0.35 to 1.45 m/s^2 in tractors, and 0.79 to 1.04 m/s^2 in fork-lift trucks and freight-container tractors. The findings of both cross-sectional and cohort epidemiologic studies suggested an increased risk for LBP disorders among occupational groups exposed to WBV when compared to unexposed control groups including either sedentary workers such as administrative officers or manual workers such as maintenance operators. The results of a meta-analysis showed that after adjusting for individual characteristics and ergonomic and psychological risk factors at work, there was a significant increase in the combined prevalence odds ratio (POR) for 12-month prevalence of LBP in occupations with exposure to WBV from industrial vehicles (summary POR: 2.3, 95% confidence interval (CI) 1.8-2.9). An excess risk for sciatic pain (summary POR: 2.0, 95% CI 1.3-2.9) and lumbar disc disorders, including herniated disc (summary POR: 1.5, 95% CI: 0.9-2.4 for cross-sectional studies; summary incidence density ratio: 1.8, 95% CI: 1.1-3.1 for cohort studies) was also found in the WBV-exposed occupational groups compared with the control groups.

These findings tend to confirm that occupational exposure to WBV is associated with an increased risk for LBP, sciatic pain, and degenerative changes in the spinal system, including lumbar intervertebral disc disorders. Biodynamic and physiological experiments have shown that seated WBV exposure can affect the spine by mechanical overloading and excessive muscular fatigue, supporting the epidemiologic findings of a possible causal role of WBV in the development of (low) back troubles (7). However, owing to the cross-sectional design of the majority of the reviewed studies, this epidemiologic evidence is not sufficient to outline a clear exposure-response relationship between WBV exposure and (lower back disorders.

3. Hand-transmitted vibration

3.1 General

Prolonged exposure to hand-transmitted vibration (HTV) from powered processes or tools is associated with an increased occurrence of symptoms and signs of disorders in the vascular, neurological and osteoarticular systems of the upper limbs (1). The complex of these disorders is called *hand-arm vibration (HAV) syndrome*. The vascular component of the HAV syndrome is represented by a secondary form of Raynaud's phenomenon known as vibration-induced white finger; the neurological component is characterised by a peripheral, diffusely distributed neuropathy with predominant sensory impairment; the osteoarticular component includes degenerative changes in the bones and joints of the upper extremities, mainly in the wrists and elbows. An increased risk for upper limb muscle and tendon disorders, as well as for nerve trunk entrapment syndromes, has also been reported in workers who use hand-held vibrating tools (10). The vascular and osteoarticular disorders caused by HTV are included in a European schedule of recognised occupational diseases (90/326/EEC). It is estimated that 1.7 to 5.8% of the workers in the European Countries, U.S. and Canada are exposed to potentially harmful HTV (6).

3.2 Neurological disorders

There is epidemiologic evidence for a greater occurrence of digital tingling and numbness, deterioration of finger tactile perception, and loss of manipulative dexterity in occupational groups using vibrating tools than in control groups not exposed to HTV (1, 6, 7). In epidemiologic surveys of vibration-exposed workers, the prevalence of peripheral sensorineural disorders was found to vary from a few percent to more than 80% (1).

Neurophysiological studies have suggested that sensory disturbances in the hands of vibration-exposed workers are likely due to vibration-induced impairment to various skin mechanoreceptors (Meissner's corpuscles, Pacinian corpuscles, Merkel cell neurite complexes, Ruffini endings) and their afferent nerve fibres. Electron microscopic studies of human finger biopsy specimens suggest that hand-transmitted vibration can provoke perineural fibrosis, demyelination, axonal degeneration and nerve fibre loss.

The neurological component of the HAV syndrome is currently staged according to the scale proposed at the Stockholm Workshop 86 (12). The sensorineural (SN) scale consists of three stages (SN1, SN2, SN3) according to the symptoms complained and the results of clinical examination and objective tests.

Clinical and epidemiologic surveys have revealed an increase in sensorineural disorders with the increase of daily vibration exposure, duration of exposure, or lifetime cumulative vibration dose. The currently available epidemiologic data, however, are insufficient to outline the form of a possible exposure-response relationship for vibration-induced neuropathy.

Some cross-sectional and case-control studies have shown an increased occurrence of symptoms and signs of entrapment neuropathies, mainly carpal tunnel syndrome (CTS), in occupations involving the usage of vibrating tools (10). CTS is also common in job categories whose work tasks involve high-force and repetitive hand wrist movements. The independent contribution of vibration exposure and physical work load (forceful gripping, heavy manual labour, wrist flexion and extension), as well as their interaction, in the etiopathogenesis of CTS have not yet been established in epidemiologic studies of workers who handle vibratory tools. It has been suggested that ergonomic risk factors are likely to play the dominant role in the development of CTS. As a result, to date it is hard to draw a specific relation between CTS and exposure to HTV.

3.3 Bone and joint disorders

Vibration-induced bone and joint disorders are a controversial matter. Various authors consider that disorders of bones and joints in the upper extremities of workers using hand-held vibrating tools are not specific in character and similar to those due to the ageing process and to heavy manual work (1, 6). Early radiological investigations had revealed a high prevalence of bone vacuoles and cysts in the hands and wrists of vibration-exposed workers, but more recent studies have shown no significant increase with respect to control groups made up of manual workers (1). An increased risk for wrist osteoarthrosis and elbow arthrosis and osteophytosis has been reported in coal miners, road construction workers and metal-working operators exposed to shocks and low frequency vibration (<50 Hz) of high magnitude from percussive tools (pick, riveting and chisel hammers, vibrating compressors), (6). An excess prevalence of Kienbock's disease (lunate malacia) and pseudoarthrosis of the scaphoid bone in the wrist has also been reported by a few investigators (1). On the contrary, there is little evidence for an increased prevalence of degenerative bone and joint disorders in the upper limbs of workers exposed to mid- or high-frequency vibration arising from chain saws or grinding machines. It is thought that, in addition to vibration, joint overload due to heavy physical effort, awkward postures, and other biomechanical factors can account for the higher occurrence of skeletal injuries found in the upper limbs of users of percussive tools (1, 6, 7). A constitutional susceptibility might also play a role in the etiopathogenesis of premature wrist and elbow osteoarthrosis. At present, there are no epidemiologic studies that may suggest, even tentatively, an exposure-response relation for bone and joint disorders in vibration-exposed workers.

3.4 Muscle and tendon disorders

Workers with prolonged exposure to HTV may complain of muscular weakness, pain in the hands and arms, and diminished muscle force (6, 7). Vibration exposure has also been found to be associated with a reduction of hand-grip strength. In some individuals muscle fatigue can cause disability. Direct mechanical injury or peripheral nerve damage have been suggested as possible etiologic factors for muscle symptoms. Other work-related disorders have been reported in vibration-exposed workers, such as tendinitis and tenosynovitis in the upper limbs, and Dupuytren's contracture, a disease of the fascial tissues of the palm of the hand (6, 10). These disorders seem to be related to ergonomic stress factors arising from heavy manual work, and the association with HTV is not conclusive.

3.5 Vascular disorders (white finger)

Vibration-induced white finger (VWF) is recognised as an occupational disease in many industrialised countries. Epidemiologic studies have pointed out that the prevalence of VWF is very wide, from 0-5% in workers using vibratory tools in geographical areas with a warm climate to 80-100% in workers exposed to high vibration magnitudes in northern Countries (1, 6, 7).

It is believed that vibration can disturb the digital circulation making it more sensitive to the vasoconstrictive action of cold. To explain cold-induced Raynaud's phenomenon in vibration-exposed workers, some investigators invoke an exaggerated central vasoconstrictor reflex caused by prolonged exposure to harmful vibration, while others tend to emphasise the role of vibration-induced local changes in the digital vessels (e.g. thickening of the muscular wall, endothelial damage, functional receptor changes). It has also been suggested that vasoactive substances, immunologic factors or blood viscosity may play a role in the pathogenesis of VWF (1).

A grading scale for the classification of VWF has been proposed at the Stockholm Workshop 86 (12), consisting of four symptomatic stages, from mild (stage 1) to very severe (stage 4). VWF symptoms are staged according to the frequency of finger blanching attacks, the number of affected fingers and the number of affected phalanges in a given finger.

Since the late 1970s a decrease in the occurrence of VWF has been reported among active forestry workers in both Europe and Japan after the introduction of anti-vibration chain saws and administrative measures curtailing the saw usage time together with endeavours to reduce exposure to other harmful work environment factors (e.g. cold and physical stress). Recovery from VWF has also been reported among retired forestry workers. In general, there is evidence for a decrease in the prevalence of VWF in the last decade, at least among occupational groups who started to work with vibrating tools of new generation (6).

4. Occupational exposure to vibration in the European Union

On the basis of the 2nd European Survey on Working Conditions (ESWC, 1996), the European Agency for Safety and Health at Work (5) has pointed out that 24% of all workers interviewed during the survey reported being exposed to mechanical vibration in the workplaces of the EU (5). From the ESWC data, moreover, it results that 11% of the EU workforce is exposed to vibration (either HTV or WBV) for all or almost all the time during a typical workday, 6% for around _ or _ of the time, and 7% for around _ of the time. The ESWC data show that "Construction" is the industrial sector most at risk from vibration in the workplace: 49% of the employed or self employed workers in the construction industry are estimated to be exposed to HTV and/or WBV. Other industrial sectors at increased risk from vibration are "Agriculture, Hunting, Forestry and Fishing" (45%), "Electricity, Gas and Water Supply" (39%), "Mining, Quarrying and Manufacturing" (37%), "Transport, Storage and Communications" (24%), "Wholesale and Retail Trade, Repair of Motor Vehicles, Motocycles and Personal and Household Goods" (17%).

The ESWC survey identifies workers from the occupation categories "Craft and related trade workers", "Skilled agricultural and fishery workers", "Plant and machine operators and assemblers", and "Armed forces" as the occupations with the greatest exposure to vibration. For the identified industrial sectors and occupation categories, male workers are considered to be more at risk from the health effects of vibration in the workplace.

With regard to other issues associated with vibration exposure, the European Agency for Safety and Health at Work reports that "*no firm conclusions could be drawn on company size, age or employment status though comments received from the national Focal Points indicated that small businesses were most at risk because of the use of older machines, lack or awareness and resource to address the problem. The self-employed and contractors were considered to be at risk which is supported by the findings of the ESWC survey in which the self-employed were identified as being most at risk*" (5).

Four national Focal Points (Belgium, Finland, Germany, and Greece) reported a decreased trend in the number of workers exposed to vibration over the last 3-5 years, while six Focal Points (Austria, Denmark, Netherlands, Portugal, Spain, and Sweden) reported a stable trend and three Focal Points (France, Ireland, and Italy) an increased trend.

5. Protection and health surveillance of vibration-exposed workers

The prevention of injuries or disorders caused by mechanical vibration in the workplace requires the implementation of administrative, technical and medical procedures. Such procedures include technical measures aimed at elimination or reduction of hand-transmitted vibration at the source, appropriate information and advice to employers and employees, instruction to adopt safe and correct work practices, and medical preventive guidance.

The European Directive 89/391/EEC (art. 14, par. 1) states that: "*to ensure that workers receive health surveillance appropriate to the health and safety risks they incur at work, measures shall be introduced in accordance with national law and/or practices*". According to the European Directive 2002/44/EC on mechanical vibration (art. 8, par. 1), "*health surveillance, the results of which are taken into account in the application of preventive measures at a specific workplace, shall be intended to prevent and diagnose rapidly any disorder linked with exposure to mechanical vibration. Such surveillance shall be appropriate where:*

(i) the exposure of workers to vibration is such that a link can be established between that exposure and an identifiable illness or harmful effects on health;
(ii) it is probable that the illness or the effects occur in a worker's particular working conditions;
(iii) there are tested techniques for the detection of the illness or the harmful effects on health.

In any event, workers exposed to mechanical vibration in excess of the values stated in Article 3(1)(b) and (2)(b) shall be entitled to appropriate health surveillance".

The values reported in Article 3(1)(b) and (2)(b) of the Directive are the daily exposure action values for HTV and WBV expressed in terms of A(8), (see below).

In 1998, a European research network ("Vibration Injury Network", VINET) was established within the EU BIOMED 2 programme with the main scope to advance methods for the detection and prevention of injury due to occupational exposures to vibration (11). One of the objectives of VINET was the development of common procedures for HTV and WBV health surveillance, including the development of improved methods for the detection and diagnosis of disorders. In this context, protocols for the health surveillance of workers exposed to either HTV or WBV were developed. The protocols are to provide tools for assessing health effects in the upper limbs (HTV exposed workers) or in the lower back (WBV exposed workers) that can be used for health surveillance in the workplace, and in epidemiological research. The tools that were developed comprise guidelines for health surveillance, questionnaires for initial assessment and periodic medical examinations at regular intervals, and the definition of a battery of objective tests for the assessment of vibration-induced disorders. The complete material is available in the Internet (http://www.human-vibration.com).

Some of the tools developed by VINET have been adopted by the Italian Society of Occupational Medicine and Industrial Hygiene (SIMLII) for the preparation of national guidelines for the assessment of vibration exposure at the workplace and for health surveillance of vibration exposed workers (2). The SIMLII guidelines are also used as tools for continuing medical education and accreditation of occupational health physicians in Italy. Table I reports the topics treated in the SIMLII guidelines. In addition to guidelines for vibration health surveillance, the SIMLII document includes four HTV questionnaires, two WBV questionnaires, and various annexes. Among these latter, it is worth mentioning a list of medical conditions that may increase the risk of upper limb disorders in workers exposed to HTV (Table II) and a list of medical conditions that may increase the risk of disorders of the spine or other organs and structures in workers exposed to WBV (Table III).

The VINET and SIMLII documents (2, 11) point out that the aims of health surveillance are to inform the workers on the potential risk associated with vibration exposure, to assess health status and to diagnose vibration-induced disorders at an early stage. The European Directive on mechanical vibration (4) establishes that health surveillance is compulsory for workers exposed to vibration exceeding the daily exposure action values [A(8)] reported in Table IV. Moreover, the Directive requires that the employer shall take immediate action to reduce exposure if the daily exposure limit values [A(8)] have been exceeded (Table IV).

Pre-placement medical assessment and periodic clinical examinations at regular intervals should be conducted for each worker who is exposed to mechanical vibration at the workplace. It should be noted that no one symptom or sign is specific of vibration-induced disorders and that the clinical features of these disorders may be found in several other diseases. As a result, the occupational health physician should consider various clinical and laboratory tests in order to perform a differential diagnosis when the case history and the physical examination suggest the presence of symptoms or signs of vibration-induced disorders.

Table I. ***Topics treated in the guidelines of the Italian Society of Occupational Medicine and Industrial Hygiene for the assessment of vibration exposure in the workplace and for the health surveillance of vibration exposed workers (title and table of contents)***

"HEALTH DISORDERS FROM EXPOSURE TO MECHANICAL VIBRATION AT THE WORKPLACE"

CONTENTS

Table II. ***List of medical conditions that may increase the risk of upper limb disorders in workers exposed to hand-transmitted vibration. It should be noted that some of the disorders or diseases included in the table are incompatible with any work activity***

Vascular

1. **Primary Raynaud's phenomenon**
2. **Secondary Raynaud's phenomenon** caused by:
   - 2.1 Connective tissue diseases (e.g. scleroderma, systemic lupus erythematosus, dermatomyositis, polyarteritis nodosa, rheumatoid arthritis, Sjögren's disease)
   - 2.2 Occlusive vascular disease (e.g. thromboangiitis obliterans, atherosclerosis)
   - 2.3 Compression of proximal vessels (e.g. thoracic outlet syndrome, costoclavicular syndrome, hyperabduction syndrome)
   - 2.4 Trauma (e.g. following injury, fracture or surgery, frostbite)
   - 2.5 Neurogenic disorders (e.g. poliomyelitis, syringomyelia, hemiplegia)
   - 2.6 Blood abnormalities (e.g. polycythaemia vera, cryoproteinemias, macroglobulinemia, thrombocytosis)
   - 2.7 Occupational chemical agents (e.g. vinyl chloride, arsenic, nitrates)
   - 2.8 Drugs (e.g. β-adrenoceptor blocking agents, ergot preparations, clonidine, chemotherapeutic agents, cyclosporin)
   - 2.9 Miscellaneous (e.g. vasculitis, arteriovenous fistula, fibromyalgia, hypothyroidism, reflex sympathetic dystrophy, neoplasms)
3. **Peripheral vascular disorders**
   - 3.1 Arteriosclerosis obliterans
   - 3.2 Thromboangiitis obliterans (Buerger's disease)
   - 3.3 Acquired arteriovenous fistulas
   - 3.4 Erythromelalgia
4. **Vascular disorders secondary to malformations, injuries, fractures, or surgery in the hand, arm, or neck**

Neurological

1. **Peripheral nerve entrapment** (e.g. carpal tunnel syndrome, pronator syndrome, Guyon's syndrome, cubital tunnel syndrome)
2. **Peripheral neuropathy** (e.g. diabetic, alcoholic and toxic neuropathies, cervical radiculopathy)
3. **Disorders of the central nervous system** (e.g. compressive myelopathy, multiple sclerosis, degeneration of the spinal cord)
4. **Neurological disorders secondary to malformations, injuries, fractures, or surgery in the hand, arm, or neck**

Musculoskeletal

1. **Severe tendinitis or tenosynovitis in the hand-wrist, elbow, or shoulder** (e.g. de Quervain's tendinitis, lateral epicondylitis, shoulder tendinitis)
2. **Severe unspecific cervicobrachial disorders**
3. **Severe Dupuytren's contracture**
4. **Severe degenerative bone and joints disorders in the upper limbs and the neck**
5. **Severe deformities of the bone and joints of the upper limbs secondary to malformations, injuries, fractures, or surgery**
6. **Severe myopathies** (e.g. primary fibromyalgia, myofascial syndrome, alcoholic myopathy, drug-induced myopathy, muscle pain syndrome of unknown etiology)

Table III. ***List of medical conditions that may increase the risk of disorders of the spine or other organs and structures in workers exposed to whole-body vibration***

Disorders of the spine

1. Distinct premature (not related to age) degenerative changes in the spine
2. Disorders of the intervertebral disc (with or without radicular syndromes)
3. Active inflammatory conditions of the spine
4. Manifest acquired or congenital deformation of the spine
5. Increased stiffness of the spine (e.g. following surgical treatment)
6. Earlier spinal injuries with fractures of vertebrae
7. Recurrent episodes of chronic back pain

Other conditions

1. Severe neck-shoulder disorders
2. Chronic gastritis and/or gastric or duodenal ulcers
3. Vestibular disorders
4. Pregnancy

Table IV. ***Daily exposure action values and daily exposure limit values for hand-transmitted vibration (HTV) and whole-body vibration (WBV) according to the European Directive 2002/44/EC on mechanical vibration (4). A(8) is the daily vibration exposure value normalised to an eight-hour reference period, in m/s^2 (see text for the technical definitions of A(8), r.m.s., and VDV)***

A(8)	HTV	WBV
Daily exposure action value	2.5 m/s^2 (r.m.s.)	0.5 m/s^2 (r.m.s.) 9.1 m/s$^{1.75}$ (VDV)
Daily exposure limit value	5 m/s^2 (r.m.s.)	1.15 m/s^2 (r.m.s.) 21 m/s$^{1.75}$ (VDV)

A pre-placement medical examination should be offered to each worker who will be exposed to mechanical vibration on the job. The main purposes of pre-placement health assessment are to make the worker aware of the hazards connected with exposure to vibration, to obtain baseline health data for comparison with the findings of subsequent periodical health examinations, and to verify the presence of pathological conditions which may increase the risk of adverse health effects due to vibration exposure (see Tables II and III). The pre-placement medical evaluation must be performed according to the principles and practice of occupational medicine and shall include the case history, a complete physical examination and, if necessary, special diagnostic investigations according to the clinical judgement of the physician.

The pre-placement examination should be followed by periodic health re-assessment with a regular interval. For HTV, periodic medical examination should be made available at least annually to all workers who use vibratory tools. For WBV, periodic medical examination should be made available at least every two years to all workers who are exposed to WBV. If an increase in vibration exposure or a change in health status have occurred, the medical re-examination should be offered at shorter intervals at the discretion of the attending physician. At the periodic medical examination, any change in work practices with vibratory tools should be reported in a follow-up questionnaire. Moreover, any illness or injury occurred since the last examination, any symptom possibly related to vibration exposure, as well as the findings of the physical examination, should be reported. The reported findings for the individual should be compared with those of previous examinations.

Special diagnostic investigations should be decided by the physician on the basis of the worker's symptoms and the results of the clinical examination. For HTV, vascular investigations (cold test with measurement of finger skin temperature and/or finger systolic blood pressure), neurological investigations (thermal and vibrotactile perception thresholds, neurophysiological testing), muscle strength investigations (pinch and hand grip strength), and radiological investigations of the upper limbs are mentioned in the VINET and SIMLII reports (2, 11). For WBV, special investigations include X-ray, CT-scan, or MRI of the lumbar spine. However, these radiological procedures are not acceptable in absence of positive symptoms and signs of spinal disorders.

Avoidance or reduction of vibration exposure for workers affected with disorders caused by HTV or WBV should be decided after considering the severity of symptoms, the characteristics of the entire working process, and other aspects related to the company's medical policy and the legislation of the country. Since there is clinical and epidemiological evidence that some vibration-induced disorders, mainly the vascular component of the HAV syndrome, may be reversible when vibration exposure is ceased, the physician should discuss with the employee the possibility of his/her re-employment in working practices with vibratory tools if previous symptoms and signs have improved sufficiently according to well-established medical criteria (2, 6).

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