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Criteria for case definitions for upper limb and lower back disorders caused by mechanical vibration

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Key words
Upper limb; lower back; occupational disease; vibration exposure; work-related diseases

Summary
Background and Objectives: *This paper provides an overview on the evaluation and assessment of vibration exposure at the workplace, the long-term health effects caused by occupational exposure to hand-transmitted vibration and whole-body vibration, and the criteria for case definitions for vibration-induced upper limb and lower back disorders. Excessive exposure to hand-transmitted vibration from powered processes or tools is associated with an increased occurrence of symptoms and signs of disorders in the vascular, neurological and musculoskeletal systems of the upper limbs. The complex of these disorders is called hand-arm vibration syndrome. Long-term occupational exposure to intense whole-body vibration is associated with an increased risk for disorders of the lumbar spine and the connected nervous system.* **Discussion and Conclusions:** *The medical tools for the management of cases with suspected vibration-induced disorders include the case history, a complete physical examination, and special diagnostic investigations. The criteria for case definitions for upper limb disorders caused by hand-transmitted vibration (vascular, neurological, and musculoskeletal) and for lower back disorders caused by whole-body vibration are discussed on the basis of the guidelines suggested by the Italian Society of Occupational Medicine and Industrial Hygiene.*

Riassunto
«Criteri per la definizione delle malattie muscolo-scheletriche dell'arto superiore e del rachide lombare derivanti da esposizione a vibrazioni». *In questo studio sono discussi i rischi derivanti dall'esposizione a vibrazioni meccaniche negli ambienti di lavoro e i possibili criteri per il riconoscimento dell'eziologia professionale delle patologie che possono insorgere nei lavoratori che usano utensili vibranti o conducono macchine e/o veicoli di trasporto. Un'intensa e prolungata esposizione a vibrazioni trasmesse al sistema mano-braccio 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, definiti, con termine unitario, sindrome da vibrazioni mano-braccio. Un'esposizione prolungata a vibrazioni trasmesse al corpo intero in autisti di veicoli pubblici e macchine industriali ed agricole è associata ad una aumentata occorrenza di lombalgie, lombosciatalgie ed alterazioni radiologiche a carico del rachide lombare. Gli strumenti per la gestione sanitaria dei possibili casi di patologie causate dalle vibrazioni meccaniche comprendono la storia occupazionale e clinica, un esame obiettivo completo e indagini di laboratorio e di diagnostica per immagini. Vengono presentati i criteri diagnostici per la definizione di malattia professionale o malattie correlate con il lavoro negli esposti a vibrazioni meccaniche sulla base delle linee guide suggerite dalla Società Italiana di Medicina del Lavoro e Igiene Industriale.*

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Introduction

Mechanical vibration arises from a wide variety of processes and operations performed in industry, mining and construction, forestry and agriculture, and public utilities. ***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. ***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 (17).

Article 2 of the Directive 2002/44/EC of the European Parliament and of the Council on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration), defines "hand-arm vibration" as "*the mechanical vibration that, when transmitted to the human hand-arm system, entails risks to the health and safety of workers, in particular vascular, bone or joint, neurological or muscular disorders*", and "whole-body vibration" as "*the mechanical vibration that, when transmitted to the whole body, entails risks to the health and safety of workers, in particular lower-back morbidity and trauma of the spine*" (10).

According to the 3rd European Survey on Working Conditions (30), about 24% of all workers interviewed during the survey reported being exposed to mechanical vibration in the workplaces of the European Union. In Europe, craft workers, machine operators, agricultural workers, work force involved in elementary occupations, and armed forces are the occupations with the greatest exposure to vibration from hand tools, machinery, etc. In Italy, it is estimated that about 26% of workers are exposed to mechanical vibration. Of them, 5.4% are exposed all of the time during a workshift, 5.6% almost of the time, 2.2% around 3/4 of the time, 5.7% around half of the time, and 6.8% around 1/4 of the time.

Exposure to harmful vibration at the workplace can induce several complaints and health disorders, mainly in the upper limbs and the lower back (2, 13, 17). This paper provides an overview on the evaluation and assessment of vibration exposure at the workplace, as well as on the long-term health effects caused by occupational exposure to hand-transmitted vibration and whole-body vibration. The criteria for case definitions for vibration-induced upper limb and lower back disorders, as suggested by the Italian Society of Occupational Medicine and Industrial Hygiene, are presented (6).

Evaluation and assessment of vibration exposure

The human response to vibration depends mainly on the magnitude, frequency and direction of the vibration signal (17). The magnitude of vibration is quantified by its displacement (m), its velocity (ms^{-1}), or its acceleration (ms^{-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 (ms^{-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 (17). 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 5 to 1500 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 (21-23). 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, 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. $a_{hv}=(a_{hwx}^2+a_{hwy}^2+a_{hwz}^2)^{1/2}$ in ms^{-2} r.m.s. (22, 23).

The vibration total value has also been proposed for the evaluation of the health effects of whole-body vibration if no dominant axis of vibration exists. 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 $a_v=(k_x^2a_{wx}^2+ k_y^2a_{wy}^2+k_z^2a_{wz}^2)^{1/2}$, where k=1.4 for x- and y-axes and k=1 for z-axis (21).

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 (21) 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. $ms^{-1.75}$).

According to the European Directive 2002/44/EC (10), daily exposure to hand-transmitted vibration is assessed in terms of 8-h energy-equivalent frequency-weighted vibration total value ($A(8)$ in ms^{-2} r.m.s.), calculated from the magnitude of the vibration total value (a_{hv}) and the daily exposure duration (T_e in hours):

$$A(8) = a_{hv}\,(T_e/T_8)^{1/2}\ (ms^{-2}\ r.m.s.)$$

Daily exposure to whole-body vibration is also based on $A(8)$ (ms^{-2} r.m.s.), but calculated from the highest (r.m.s.) value of the frequency-weighted accelerations ($1.4a_{wx}$, $1.4a_{wy}$, or a_{wz}). Moreover, the EU Directive suggests the highest *vibration dose value* (*VDV*) of the frequency-weighted accelerations as an alternative measure of WBV exposure ($1.4VDV_{wx}$, $1.4VDV_{wy}$, or VDV_{wz}) when vibration from machines or vehicles contains acceleration peaks or shocks.

The EU Directive 2002/44/EC establishes “daily exposure action values” and “daily exposure limit values” for both hand-transmitted vibration and whole-body vibration (table 1). Workers shall not be exposed above the exposure limit values. If the exposure action values are exceeded, the employers shall implement administrative, technical and medical measures with the aim to protect workers against the risks arising from vibration exposure.

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), (17).

Table 1 - *Daily exposure action value and daily exposure limit value for hand-arm vibration (HAV) and whole-body vibration (WBV) according to the EU Directive 2002/44/EC, (see text for the definitions of A(8) and VDV)*

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

Long-term health effects of mechanical vibration

Hand-transmitted vibration

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 (2, 4, 15, 17). The complex of these disorders is called *hand-arm vibration syndrome*. The *vascular component* of the 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 (2, 4). The vascular and osteoarticular disorders caused by HTV are included in a European schedule of recognised occupational diseases (9).

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 (4). 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% (13).

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 (7). 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 (table 2).

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 (13). CTS is also common in job categories whose work tasks involve high-force and repetitive hand wrist movements (18). 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.

Table 2 - *The Stockholm Workshop scale for the sensorineural stages of the hand-arm vibration syndrome*

Stage	Symptoms and signs
SN0	Exposed to vibration but no symptoms
SN1	Intermittent numbness, with or without tingling
SN2	Intermittent or persistent numbness, reduced sensory perception
SN3	Intermittent or persistent numbness, reduced tactile discrimination and/or manipulative dexterity

Bone and joint disorders

Vibration-induced bone and joint disorders are a controversial matter (4, 13, 14, 17). 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. 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. 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). 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. 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. 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.

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 (13). 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. These disorders seem to be related to ergonomic stress factors arising from heavy manual work, and the association with HTV is not conclusive.

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 the past among workers exposed to high vibration magnitudes in northern Countries (2, 13, 15, 17).

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 (17).

Clinically, VWF is characterised by episodes of white fingers caused by spastic closure of the digital arteries. A blue discoloration of the fingers (cyanosis) may follow. The attacks are usually triggered by cold and last from 5 to 30-40 minutes. A complete loss of tactile sensitivity may be experienced during an attack. In the recovery phase, commonly accelerated by warmth or local massage, redness (hyperaemia) may appear in the affected fingers as a result of a reactive increase of blood flow in the cutaneous vessels. In the rare advanced cases, repeated and severe digital vasospastic attacks can lead to trophic changes (ulceration or gangrene) in the skin of the fingertips.

A grading scale for the classification of VWF has been proposed at the Stockholm Workshop 86 (16), 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 (table 3).

In Annex C to International Standard ISO 5349-1 (22), the following tentative relationship between vibration exposure and finger blanching (VWF) is suggested:

$$D_y = 31.8\, A(8)^{-1.06}$$

Table 3 - *The Stockholm Workshop scale for the classification of cold-induced Raynaud's phenomenon in the hand-arm vibration syndrome*

Stage	Symptoms
0	No attacks of finger blanching
1	Occasional attacks affecting only the tips of one or more fingers
2	Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers
3	Frequent attacks affecting all phalanges of most fingers
4	As in stage 3, with trophic skin changes in the finger tips

where *A*(8) is the daily vibration exposure (8-h energy-equivalent vibration total value at a surface in contact with the hand), and *Dy* is the group mean total (lifetime) exposure duration, in years.

The ISO exposure-response relationship gives the values of the daily vibration exposure *A*(8) which may be expected to produce episodes of finger blanching in 10 % of workers exposed for a given number of years *Dy*. For instance, a daily vibration exposure, *A*(8), of 7 ms^{-2} r.m.s. should be associated with an 10% occurrence of VWF in a worker group after about 4 years of exposure duration.

The prognosis of VWF is still uncertain. Studies have reported that VWF may improve, persist or worsen in workers with current or previous exposure to hand-transmitted vibration. It has been suggested that cessation or reduction of vibration exposure may be associated with some reversibility of VWF, but the rate of remission of vasospastic symptoms over time is not well-known (4, 13). However, 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. Nevertheless, it has been reported that the reversibility of VWF is inversely related to the stage of VWF at retirement, age and duration of exposure after the first episode of finger blanching (13). In general, there is evidence for a decrease in the occurrence of VWF in the last two decades, at least among occupational groups who started to work with vibrating tools of new generation.

Other possible vibration-induced disorders

A few clinical and epidemiologic studies have reported that exposure to HTV can aggravate the risk of noise-induced hearing loss and provoke disturbances of the central nervous system (4, 13, 17). To date, no exposure-response relationship can derived from the findings of the studies which have investigated these disorders in occupational groups operating vibratory tools.

Whole-body vibration

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 (2, 3, 5, 8, 12, 13, 19, 28, 35, 36). 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 whole-body vibration (13, 36). However, there is a weak epidemiologic support for vibration-induced disorders of organ systems other than the lower back. In some Countries (e.g. Belgium, France, Germany, The Netherlands), (low) 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 may be compensated (20).

Low back disorders and WBV exposure

There is strong epidemiologicalal evidence that occupational exposure to WBV is associated with an increased risk of low back pain, sciatic pain, and degenerative changes in the spinal system, including lumbar intervertebral disc disorders (2, 5, 13, 19). Several epidemiologicalal studies have suggested a trend for an increasing risk of low back pain with increasing exposure to WBV (5).

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. 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 (5, 8). 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.

However, biodynamic and physiological experiments have shown that seated vibration exposure can affect the spine by mechanical overloading and excessive muscular fatigue, supporting the epidemiological findings of a possible causal role of whole-body vibration in the development of (low) back troubles (5, 12, 17). Nevertheless, owing to the cross-sectional design of the majority of the epidemiologicalal studies, this epidemiological evidence is not sufficient to outline a clear exposure-response relationship between WBV exposure and (low) back disorders (5, 13).

Management of cases with vibration-induced disorders

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 (33). 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. The tools developed by VINET include 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.

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, the implementation of health surveillance of vibration-exposed workers, and the management of cases affected with vibration-induced disorders (6).

According to the VINET and SIMLII guidelines (6, 33), pre-placement medical assessment and periodic clinical examinations at regular intervals should be conducted for each worker exposed to mechanical vibration at the workplace. It should be noted that no one sign or symptom is specific of vibration-induced injuries and that the clinical features of the 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 possibly related to occupational exposure to vibration.

Criteria for case definitions for upper limb disorders caused by hand-transmitted vibration

The medical evaluation of workers exposed to hand-transmitted must be performed according to the principles and practice of occupational medicine and shall include the case history, a complete physical examination, and special diagnostic investigations according to the clinical judgement of the physician (33).

Information on how to collect a comprehensive case history (family, social, work, and personal health history) and to perform a detailed physical examination with special reference to the peripheral vascular, neurological, and musculoskeletal systems can be found at http://www.humanvibration.com (33).

The peripheral neurological and vascular signs and symptoms noted during the examination should reported and staged according to the Stockholm scales (tables 2 and 3). A numerical system for symptoms of finger whiteness has been proposed as a means of scoring severity (17). This method may be useful for monitoring progression or regression of symptoms in individual fingers. It should be noted that both the Stockholm scales and the numerical scoring system have limitations. However, they are currently accepted as a pragmatic compromise and may be used in clinical work and epidemiological studies (37).

According to the report of a working group at the Stockholm Workshop 94 (37), a medical interview is the best available method for the diagnosis of VWF. Therefore, in addition to the findings of the questionnaire investigation, the anamnestic diagnosis of VWF should be validated with a medical interview. The following minimal requisites for the anamnestic diagnosis of currently active VWF in a medical interview have been suggested:

(i) cold provoked episodes of well demarcated distal whiteness in one or more fingers (a history of cyanosis (blueness) alone is not acceptable immediately as diagnostic discolouration of VWF and further investigation for other secondary causes and/or diseases is recommended);

(ii) first appearance of white finger after start of professional exposure to hand-arm vibration and no other probable causes of Raynaud's phenomenon;

(iii) VWF is currently active if episodes have been noticed during the last two years. If no episodes have occurred for more than two years, VWF has ceased, provided there has been no significant change in cold exposure.

Special diagnostic investigations should be decided by the physician on the basis of the worker's symptoms and the results of the clinical examination. Screening and special investigations may be required (i) to establish a clinical diagnosis of the hand-arm vibration syndrome, (ii) to achieve accurate staging of the syndrome, (iii) to make differential diagnosis, and (iv) for medicolegal purposes.

It should be noted that VWF is considered an occupational disease because there is experimental, clinical, and epidemiological evidence that the aetiogical factor is exposure to hand-transmitted vibration. Instead, neurological and musculoskeletal disorders in users of vibratory tools should be considered work-related diseases since ergonomic risk factors (repetitiveness, force, awkward posture), in addition to hand-transmitted vibration, may contribute to the onset and the development of upper limb disorders in the exposed workers.

Various laboratory diagnostics of upper limb disorders induced by hand-transmitted vibration have been discussed in the Stockholm Workshop 94 and consensus reports have been published in an issue of Arbete och Hälsa (37).

Vascular investigations

The vascular assessment of the hand-arm vibration syndrome is mainly based on cold provocation tests with visual inspection of changes in finger colour, recording of recovery times of finger skin temperature, and/or measurement of finger systolic blood pressure. The cold test for the assessment of peripheral vascular function should be conducted according to the recommendations of international standard ISO 14835 – Part 1 (measurement and evaluation of finger skin temperature) and Part 2 (measurement and evaluation of finger systolic blood pressure) (26, 27).

The observation of a finger blanching attack after cold water immersion or the detection of an abnormal digital blood pressure after a standardised cooling procedure (e.g. zero pressure or a digital pressure at 10°C <60-70% of the pressure at 30°C) are the most supportive objective tests for a diagnosis of cold-induced Raynaud's phenomenon (37).

It should be noted that a negative cold test does not exclude the diagnosis of Raynaud's phenomenon in a subject with a reliable anamnestic history of white fingers (37).

Table 4 reports the criteria suggested by the SIMLII guidelines for the recognition of the occu-

Table 4 - *Criteria for the recognition of vibration-induced white finger (VWF) as an occupational disease*

Clinical assessment: positive medical history according to the minimal requisites for the anamnestic diagnosis of currently active VWF (Stockholm Workshop 1994)

AND

Laboratory evaluation: abnormal test findings during cold provocation: (i) visual inspection of changes in finger colour; (ii) prolonged finger rewarming time; or (iii) abnormal reduction of finger systolic blood pressure

Table 5 - *Criteria for the recognition of peripheral neurological disorders as a work-related disease in users of vibratory tools*

Clinical assessment: sensory (tingling, numbness), more rarely also motor, disturbances in the upper limbs after start of professional usage of vibratory tools and no other probable causes of peripheral neuropathy

AND

Laboratory evaluation: abnormal sensory tests (e.g. thresholds for heat, cold and vibration, aesthesiometry, manipulative dexterity, grip and pinch strength) and/or abnormal electrophysiological tests (e.g. sensory and motor nerve conduction velocities)

pational origin of vibration-induced vascular disorders.

Neurological investigations

The neurological assessment of the hand-arm vibration syndrome includes several psychophysical and neurophysiological tests. The experts of the Stockholm Workshop 94 (37) recommend the use of vibration perception thresholds (single or multi frequency) and aesthesiometry (gap detection) for testing the function of various skin mechanoreceptors and their connected A-b myelinated fibres. Thermal perception thresholds are useful to investigate the function of unmyelinated C-fibres (hot thermoreceptors) and A-d fibres (cold thermoreceptors).

Vibrotactile perception thresholds for the assessment of nerve dysfunction should be conducted according to the recommendations of International Standard ISO 13091 – Part 1 (methods of measurement at the fingertips) and Part 2 (analysis and interpretation of measurements at the fingertips) (24, 25).

The measurement of sensory and motor nerve conduction velocities in the upper and lower limbs is recommended for the diagnosis of peripheral nerve entrapments (e.g. median and ulnar nerves at the wrist and elbow) and generalised polyneuropathies. The diagnosis of carpal tunnel syndrome should be based on clinical and electrodiagnostic investigations according to the consensus criteria by Rempel et al. (32) and the American Association of Electrodiagnostic Medicine (1).

Electromyography and F-response should be also considered if proximal disorders are suspected (e.g. cervical disorders, rhizopathy).

The Purdue pegboard (assembly of pins, collars, and washers) is considered a useful testing method to measure gross movements of fingers, hands and arms and to evaluate fingertip dexterity.

Table 5 reports the criteria suggested by the SIMLII guidelines for the recognition of the occupational origin of vibration-induced neurological disorders.

Musculoskeletal disorders

The quantitative evaluation of muscle force in the hand can be performed by means of a dynamometer to measure grip strength and a pinch gauge to measure tip, key and palmar pinch strength. Standardised testing procedures and normative data for adult males and females are available in the scientific literature (29).

X-ray films of the shoulders, elbows, wrists and hands for a radiological diagnosis of bone and joint disorders are usually required in those countries in which vibration-induced osteoartropathy in the upper limbs is recognised as an occupational disease. Sometime, radiological examination of the cervical spine and ribs may be useful to exclude the presence of thoracic outlet syndrome or costoclavicular syndrome.

Table 6 reports the criteria suggested by the SIMLII guidelines for the recognition of the occupational origin of vibration-induced musculoskeletal disorders.

Table 6 - *Criteria for the recognition of upper limb musculoskeletal disorders as a work-related disease in users of vibratory tools*

Clinical assessment: ache, pain, and stiffness in the upper limbs, diminished muscle force, reduced active motions of the upper limbs; positive criteria for the clinical diagnoses of upper limb musculoskeletal disorders; symptoms and signs not related to age and no other concomitant local or systemic diseases

AND

Laboratory evaluation: (i) morphological changes in the musculoskeletal structures of the upper limbs as detected by ultrasound and/or MRI; (ii) abnormal radiological findings in the wrist and elbow joints (premature osteoarthrosis, exostoses at the sites of tendon insertions) associated with work with low frequency percussive tools

Criteria for case definitions for low back disorders caused by whole-body vibration

The medical evaluation of workers exposed to whole-body vibration shall include the case history, a complete physical examination, and special diagnostic investigations according to the clinical judgement of the physician (31, 33).

Information on how to collect a comprehensive case history (family, social, work, and personal health history) and to perform a detailed physical examination with special reference to the musculoskeletal system of the lower back can be found at http://www.humanvibration.com (33). Signs of non-organic low back pain should also be recorded during the physical examination (38).

In the absence of positive symptoms and signs and unless indicated by clinical practice guidelines, it is in general not acceptable, for the purpose of pre-placement and periodical examinations, to perform further diagnostic clinical examinations like X-ray of the lumbar spinal column, CT-scan, myelography, or MRI (31). In some guidelines on the management of occupational LBP, imaging examination is restricted to cases with neurological problems (radicular symptoms) or suspected specific spinal pathology like fractures, infections, or tumors ("red flags") (34).

The criteria for case definitions are remarkably different between countries which recognise WBV-induced low back injury as an occupational disease. As an example, table 7 reports the diagnostic criteria and exposure requirements adopted in Germany and France. In general, the diagnosis of low back disorders is based on the medical case history, the results of the physical examination and the findings from imaging procedures (X-ray films, CT-scan, or MRI).

In Germany, three pathological conditions may be compensated (11): local lumbar syndrome, mono- and polyradicular lumbar syndrome, and cauda equina syndrome. These disorders have to be associated with functional restrictions or disability which have caused withdrawal from work with vibration exposure. Positive imaging findings include degenerative changes of the edges of the vertebral body, degenerative changes of the vertebral joints and/or intervertebral disc-related changes (e.g. spondylosis, osteochondrosis, spondylarthrosis, intervertebral disc protrusion or prolapse). These degenerative processes should be not related to age. In Germany, examination by specialists in orthopaedics, surgery or neurosurgery, supported by imaging findings, is required to diagnose WBV-induced injury in the lower back.

In France, the diagnostic criteria are based on symptoms and signs of sciatic pain or radicular pain in the upper leg, associated with radiological evidence of herniation of lumbar disc L2-L3, L3-L4, L4-L5, or L5-S1.

In addition to the diagnostic criteria, a set of minimal exposure preconditions are required in both Germany and France to recognise the occupational origin of low back disorders in WBV-exposed workers. The occupational preconditions for WBV-induced spinal disorders present significant differences between the two countries. In France, an exposure duration of at least 5 years in specific driving occupations is required; the list of tasks with exposure to WBV includes driving of off-road vehicles, driving of industrial trucks or machines, and driving of articulated trucks and lorries. In Germany, the minimal exposure duration that is required for recognition of WBV-induced injury is approximately 10 years. In addition, a total vibration exposure dose of at least 1400 $(ms^{-2})^2$ has to be accumulated by the worker over his/her working

Table 7 - *Diagnostic criteria and exposure requirements for the recognition of whole body vibration-induced low back injury as an occupational disease in Germany and France*

Country	Diagnostic criteria		Exposure requirements	
	Symptoms/signs	Imaging	Minimal exposure duration	Exposure magnitude
Germany	Local lumbar syndrome, mono- or polyradicular syndrome, or cauda equina syndrome causing withdrawal from work with vibration exposure	Degenerative changes of the edges of the vertebral body, degenerative changes of the vertebral joints, disc-related changes (spondyloarthrosis, spondylosis, osteochondrosis, intervertebral disc protrusion or prolapse)	10 years (not strictly)	$a_{wz,8h}$>0.8 ms^{-2} or $a_{wz,8h}$>0.63 ms^{-2} (shock-type vibration, or poor body posture) total vibration exposure dose >1400 (ms^{-2})^2
France	Sciatic pain or radicular pain in the upper leg	Herniation of lumbar disc L2-L3, L3-L4, L4-L5, or L5-S1	5 years	Restrictive list of tasks with WBV exposure: use or driving of off-road machinery, industrial trucks or machines, articulated trucks and lorries

$a_{wz,8h}$: 8-hr energy-equivalent frequency-weighted acceleration magnitude in the vertical (z) direction

life. This limit dose is estimated on the basis of a daily vibration exposure ($a_{wz,8h}$) ≥0.8 ms^{-2} or ≥0.63 ms^{-2} (if the driver is exposed to shock-type vibration or is constrained to a poor body posture) accumulated over 220 days/year and for at least 10 years (i.e. limit dose value=(0.8 ms^{-2})^2≥220 d/yr ≥10 yrs).

In the 2003/670/EC recommendation concerning the European schedule of occupational diseases, the Commission of the European Communities included "*disc-related diseases of the lumbar vertebral column caused by the repeated vertical effectcs of whole-body vibration*" in a list of diseases suspected of being occupational in origin (Annex II, item 2.502), (9). It would be desirable that uniform diagnostic criteria and exposure requirements could be adopted by the Member States of the European Union for the recognition of WBV-induced low back disorders at the workplace. This would stimulate the process of harmonization of occupational diseases legislation in the Member Countries (20).

NO POTENTIAL CONFLICT OF INTEREST RELEVANT TO THIS ARTICLE WAS REPORTED

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